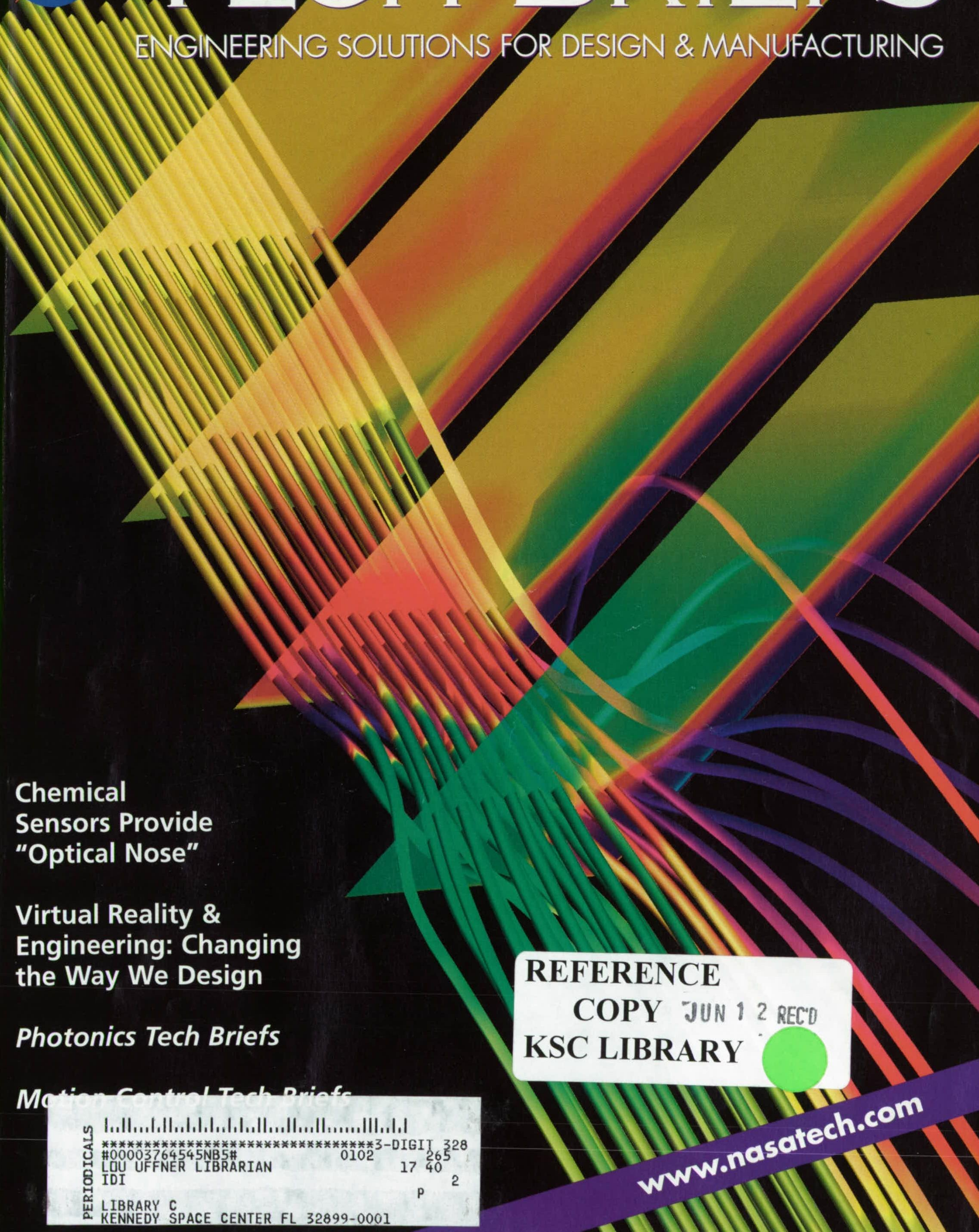
June 2001 Vol. 25 No. 6

NASA TECH BRIEFS

ENGINEERING SOLUTIONS FOR DESIGN & MANUFACTURING



Chemical Sensors Provide "Optical Nose"

Virtual Reality & Engineering: Changing the Way We Design

Photonics Tech Briefs

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NASA TECH BRIEFS

ENGINEERING SOLUTIONS FOR DESIGN & MANUFACTURING

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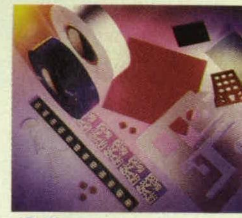

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SOLUTIONS

DEPARTMENTS

NEW FOR DESIGN ENGINEERS

SPECIAL SUPPLEMENTS

M|E|M|S

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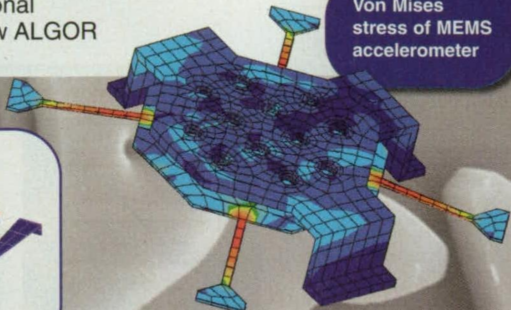
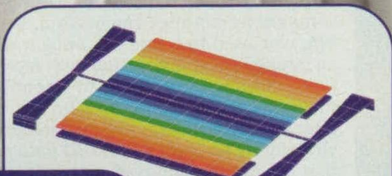


Von Mises stress of MEMS accelerometer

Electric field of MEMS radial comb motor



Displacement of MEMS switch

MEMS switch compared to a penny

ALGOR's direct-selling and high-technology business model delivers the best FEA-based simulation value for MEMS simulation in the CAE industry. ALGOR's MEMS solution links electrostatic analysis to structural analysis tools with an easy-to-use graphical user interface that works within many popular CAD systems and includes a precision FEA model building tool.

WHAT ARE MEMS?

Micro Electro Mechanical Systems (MEMS) are micromachines the size of a grain of salt or the eye of a needle that integrate mechanical elements, sensors, actuators and electronics on a common silicon substrate. MEMS applications include optical switches within telecommunication and networking systems, accelerometers in automotive airbags, inkjets in desktop printers and sensors in medical testing equipment. The emerging MEMS industry promises to make the next generation of electronic products smarter and cheaper.

ALGOR'S MEMS SOLUTION INCLUDES:

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  - Electrostatic analysis software that calculates forces due to surface charges
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  - Structural analysis software that predicts electromechanical effects driven by electrostatic forces
  - Piezoelectric material models for Mechanical Event Simulation and static stress analysis
  - Composite material models for Mechanical Event Simulation and static stress analysis
  - Thermal analysis for considering the effects of heat transfer
  - Fluid flow analysis for considering the effects of fluid dynamics
- An easy-to-use graphical user interface that enables engineers to directly apply electrostatic forces to a structural model and provides right-click functionality for applying, modifying and removing loads, constraints and finite element properties
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- Unstructured brick and tetrahedral meshing
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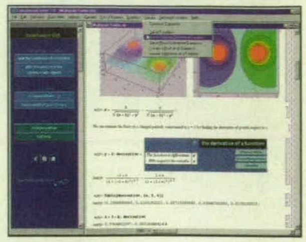
Photos courtesy of Sandia National Laboratories

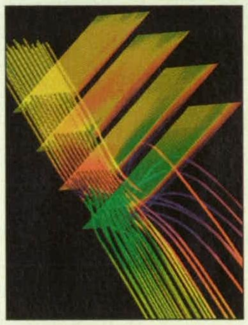
Contents *continued*

PRODUCT OF THE MONTH

CalculationCenter midmarket technical calculation software from Wolfram Research, Champaign, IL, combines algebraic operations with numerics, graphics, and a technical word processor.



ON THE COVER



Tecplot® version 9.0 technical plotting software from Amtec Engineering, Bellevue, WA, was used to create this visualization of an impinging jet interacting with a cross flow. Through the addition of OpenGL®, the new version of the software lets users interactively visualize, explore, analyze, and virtually fly through 2D and 3D data sets that consist of millions of data points. For more information on Tecplot 9.0, and to learn about other new software packages, see New on Disk on page 67.

(Data and visualization courtesy of Amtec Engineering)

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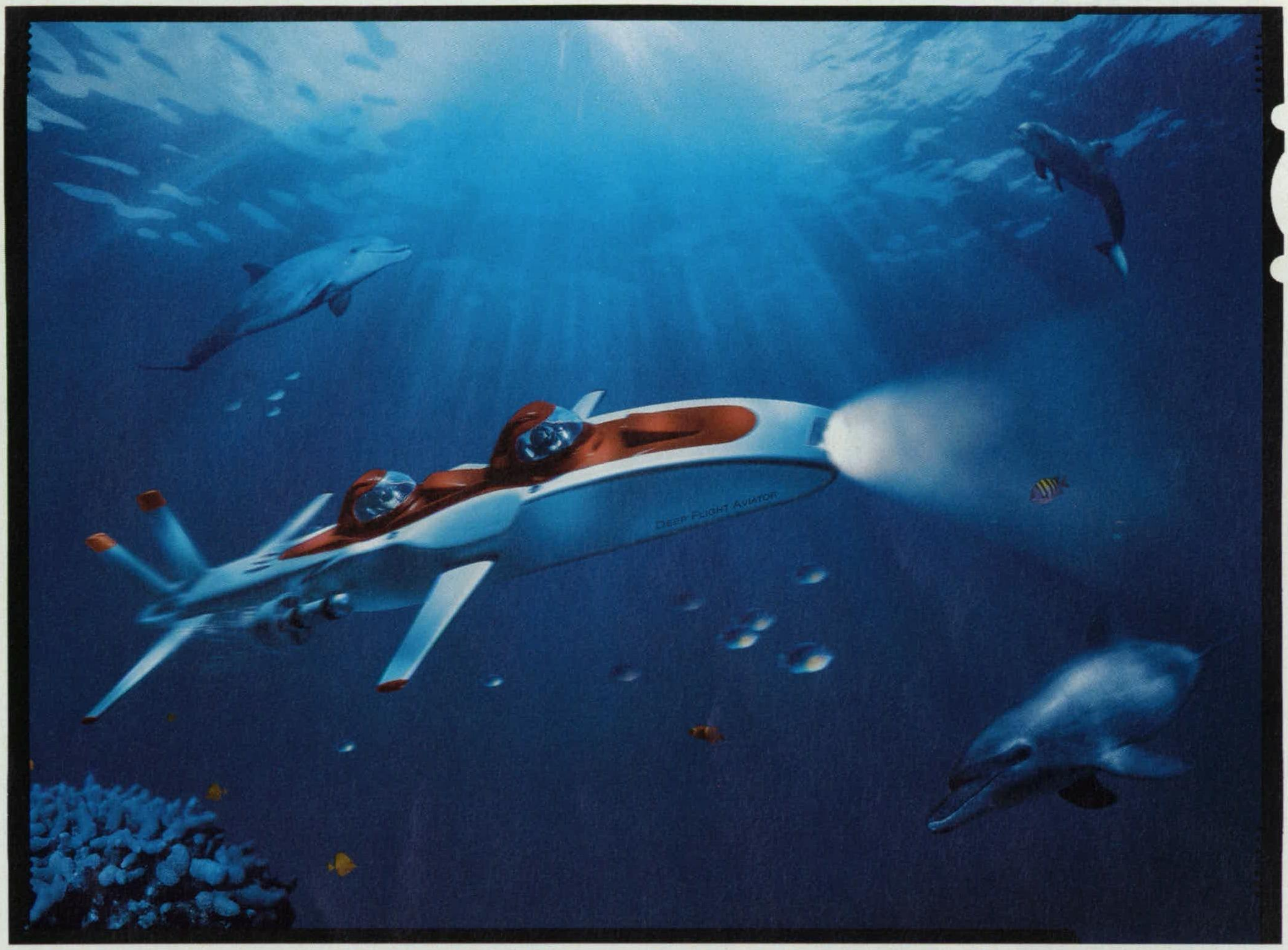
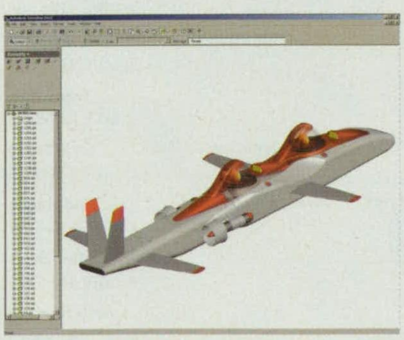


Deep Flight Aviator was invented and designed by Graham Hawkes of Hawkes Ocean Technologies using Autodesk Inventor software. To learn more, visit www.autodesk.com/nolimits.

View the online demo to see how Autodesk Inventor™ makes the transition from 2D to 3D painless.



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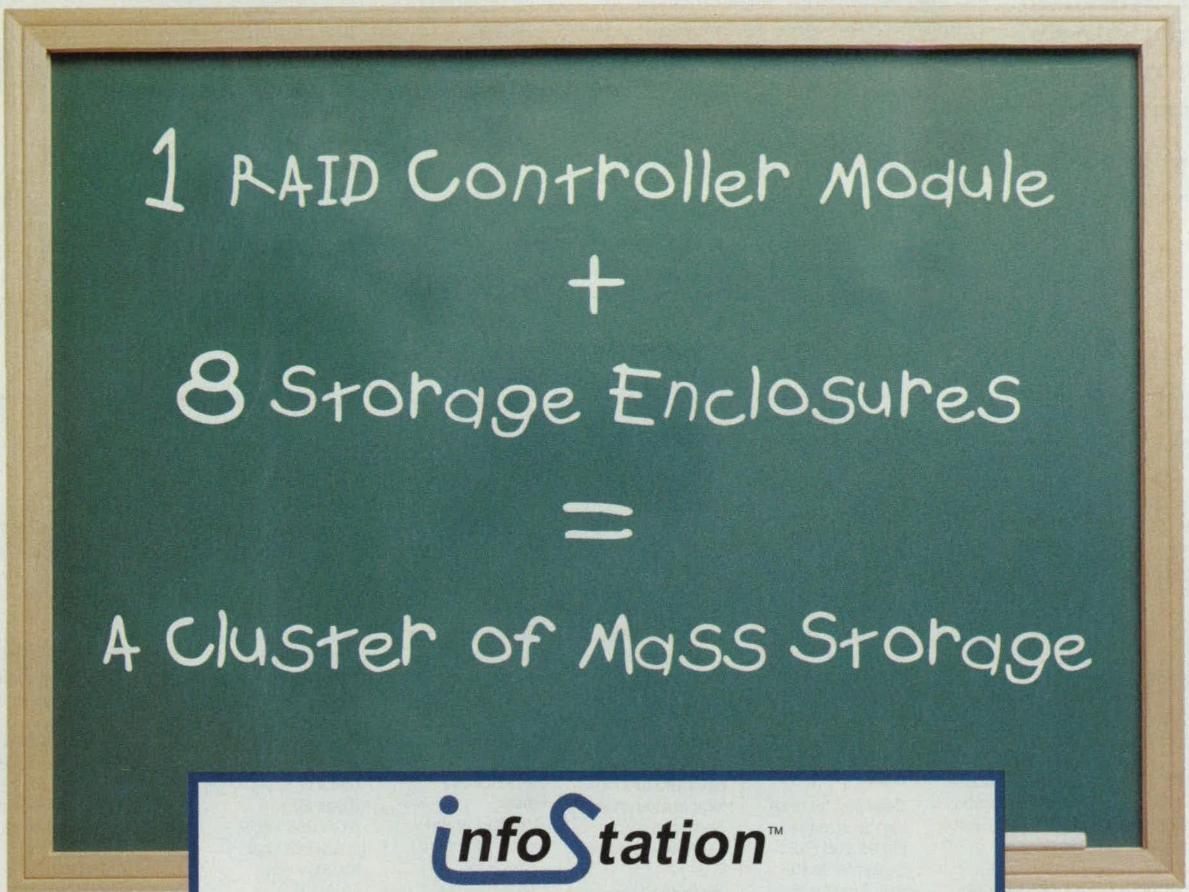

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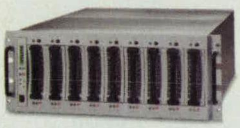

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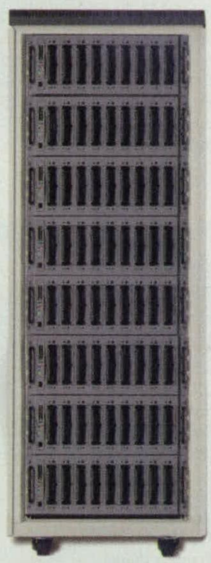

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NASA Commercial Technology Team

NASA's R&D efforts produce a robust supply of promising technologies with applications in many industries. A key mechanism in identifying commercial applications for this technology is NASA's national network of commercial technology organizations. The network includes ten NASA field centers, six Regional Technology Transfer Centers (RTTCs), the National Technology Transfer Center (NTTC), business support organizations, and a full tie-in with the Federal Laboratory Consortium (FLC) for Technology Transfer. Call (609) 667-7737 for the FLC coordinator in your area.

NASA's Technology Sources

If you need further information about new technologies presented in *NASA Tech Briefs,* request the Technical Support Package (TSP) indicated at the end of the brief. If a TSP is not available, the Commercial Technology Office at the NASA field center that sponsored the research can provide you with additional information and, if applicable, refer you to the innovator(s). These centers are the source of all NASA-developed technology.

Ames Research Center
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cblake@mail.arc.nasa.gov

Dryden Flight Research Center
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Jenny Baer-Riedhart
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jenny.baer-riedhart@dfrc.nasa.gov

Goddard Space Flight Center
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Langley Research Center
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Sam Morello
(757) 864-6005
s.a.morello@larc.nasa.gov

John H. Glenn Research Center at Lewis Field
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Larry Viterna
(216) 433-3484
cto@grc.nasa.gov

Marshall Space Flight Center
Selected technological strengths: Materials; Manufacturing; Nondestructive Evaluation; Biotechnology; Space Propulsion; Controls and Dynamics; Structures; Microgravity Processing.
Vernotto McMillan
(256) 544-2615
vernotto.mcmillan@msfc.nasa.gov

Stennis Space Center
Selected technological strengths: Propulsion Systems; Test/Monitoring; Remote Sensing; Nonintrusive Instrumentation.
Kirk Sharp
(228) 688-1929
kirk.sharp@ssc.nasa.gov

NASA-Sponsored Commercial Technology Organizations

These organizations were established to provide rapid access to NASA and other federal R&D and foster collaboration between public and private sector organizations. They also can direct you to the appropriate point of contact within the Federal Laboratory Consortium. To reach the Regional Technology Transfer Center nearest you, call (800) 472-6785.

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National Technology Transfer Center
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Ken Dozier
Far-West Technology Transfer Center
University of Southern California
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Dr. William Gasko
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NASA ON-LINE: Go to NASA's Commercial Technology Network (CTN) on the World Wide Web at **http://nctn.hq.nasa.gov** to search NASA technology resources, find commercialization opportunities, and learn about NASA's national network of programs, organizations, and services dedicated to technology transfer and commercialization.

NASA Program Offices

At NASA Headquarters there are seven major program offices that develop and oversee technology projects of potential interest to industry. The street address for these strategic business units is: NASA Headquarters, 300 E St. SW, Washington, DC 20546.

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NASA's Business Facilitators

NASA has established several organizations whose objectives are to establish joint sponsored research agreements and incubate small start-up companies with significant business promise.

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B. Greg Hinkebein
Mississippi Enterprise for Technology
Stennis Space Center, MS
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Julie Holland
NASA Commercialization Center
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Bridgette Smalley
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John Fini
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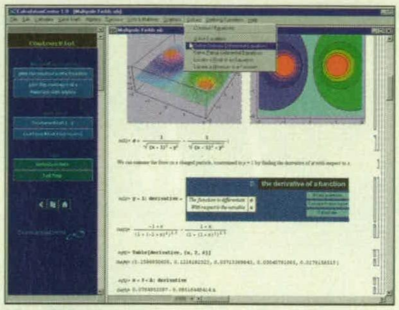
If you are interested in information, applications, and services relating to satellite and aerial data for Earth resources, contact: Dr. Stan Morain, **Earth Analysis Center,** (505) 277-3622.

UpFront

PRODUCT OF THE MONTH

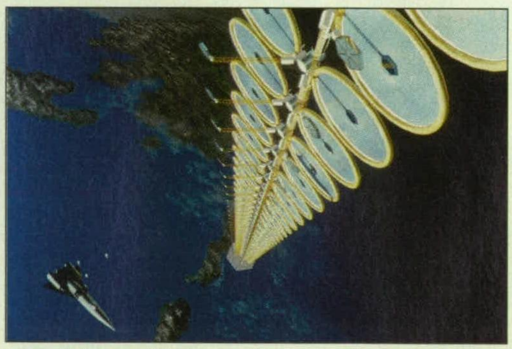


Wolfram Research, Champaign, IL, has introduced CalculationCenter midmarket technical calculation software that combines algebraic operations with numerics, graphics, and a technical word processor. The program's easy-to-use environment features InstantCalculators that guide users through each step of a calculation and remain in the document for repeated use. Smart plotting selects the range of a plot and the plot type, and works whether input is data or functions. Traditional math input automatically interprets standard math notation, using heuristics to resolve ambiguous input. Input correction automatically suggests which function a user meant to enter if the software cannot match the input. The software produces technical reports that can be distributed via hard copy, e-mail, or the Web, and is available for Windows and Mac OS platforms.

For More Information Circle No. 750

Power Struggle

The energy crisis on the West Coast is bad — and it probably will get worse as we get further into the summer. Limited power consumption and rolling blackouts are making life miserable for many Californians. With the world's population projected to rise to 10 billion people by the year 2050, supplying inexpensive, environmentally friendly electricity will be quite a challenge.



It would be possible to provide the Earth or a moon base with harnessed solar power, or travel in space without returning to Earth for fuel using a space-based solar power generator such as this SunTower. (Photo courtesy of NASA)

"We need new sources of electrical power," said John Mankins, manager of advanced concepts studies at NASA Headquarters' Office of Space Flight. "We've been studying a variety of space solar power concepts." Space solar power systems use the conversion of sunlight to electricity by beans of photovoltaic (PV) cells. Giant structures consisting of rows of PV arrays could be placed either in a geostationary Earth orbit or on the Moon. The system would collect solar energy in space, convert it to microwaves, and transmit the microwave radiation to Earth, where it would be captured by a ground antenna and transformed into electricity.

According to Dr. Neville Marzwell, technical manager of the Advanced Concepts & Technology Innovations program at NASA's Jet Propulsion Laboratory, "We now have the technology to convert the Sun's energy at the rate of 42 to 56 percent. If you can concentrate the Sun's rays through the use of large mirrors or lenses, you get more for your money because most of the cost is in the PV arrays."

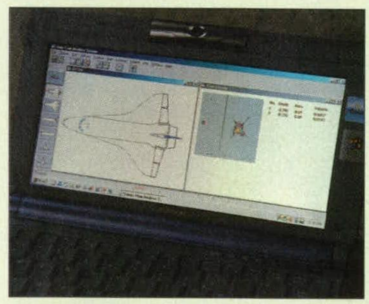
Space-based solar power offers energy from an unending source with no emissions and very little environmental impact. "You don't need cables, pipes, gas, or copper wires. We can send it to you like a cell phone call — where you want it and when you want it, in real time," said Marzwell.

For more information, visit NASA's Marshall Space Flight Center's Science@NASA Web site at http://science.nasa.gov.

Hot Stuff

The Space Shuttle's thermal tiles protect the orbiter and its crew from temperatures ranging from -250 to +3000°F during reentry. After each flight, each one of the 24,000 tiles must be inspected. Engineers from NASA's Ames Research Center in Moffett Field, CA, and the Boeing Co. in Huntington Beach, CA, have developed a handheld laser scanner for inspecting the tiles.

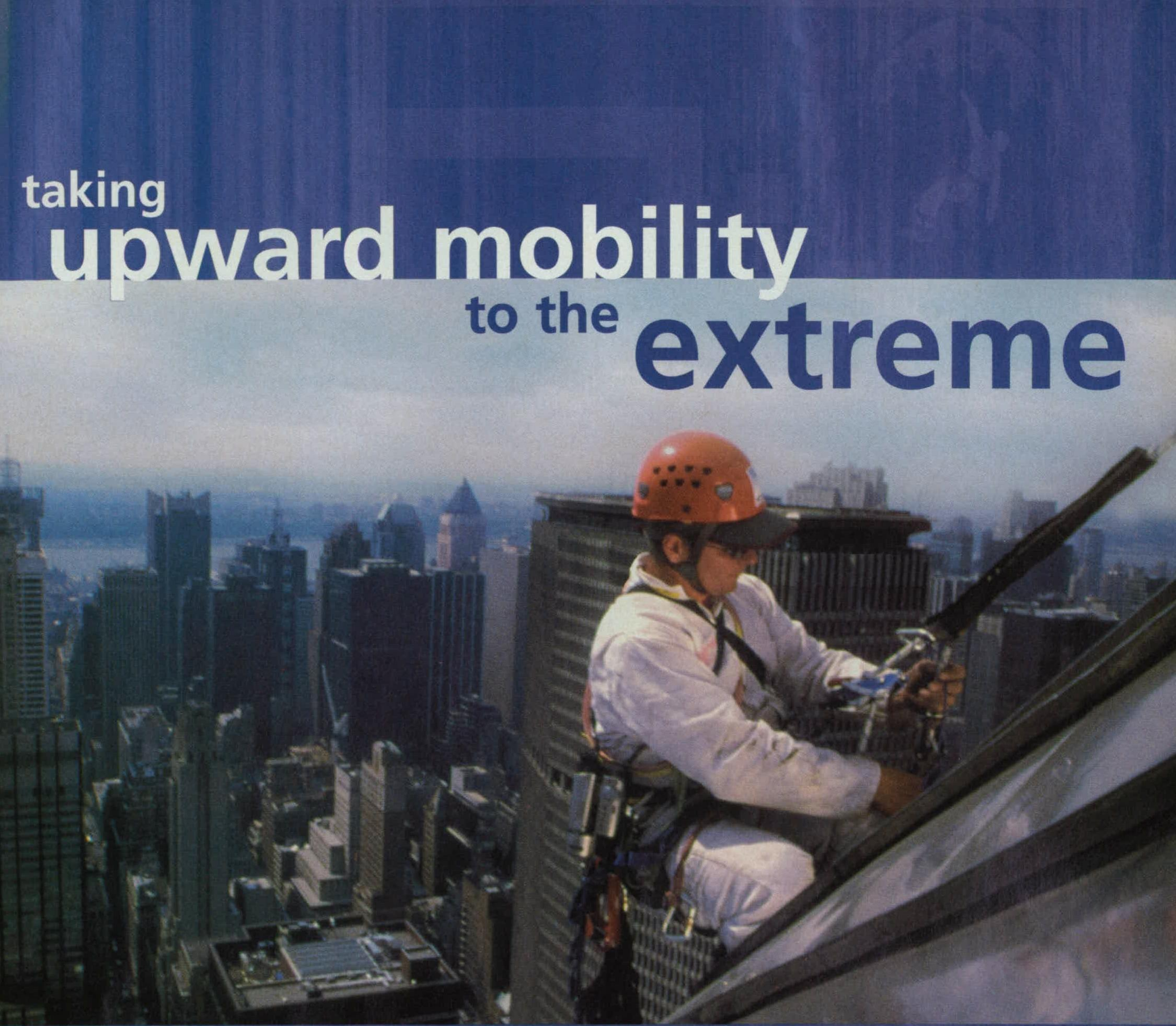
The scanner uses a digital camera and lasers in a measurement technique called laser triangulation. It is the first step toward developing an Electronic Inspection and Mapping System (EIMS) that could aid evaluation of the shuttle's Thermal Protection System (TPS). The 5 x 9" box, when placed over a tile, measures flaws within a 3 x 3" area. The scanner sends the data to a laptop computer. Software locates and characterizes the damage and generates a



3D image that indicates the depth and size of the flaw. The system also contains a database of tile fabrication and maintenance information for each tile on the orbiter being measured.

The system could make the inspection process more efficient, according to Suzy Cunningham, TPS project manager at Kennedy Space Center. That, in turn, would reduce vehicle turn-around time. The technology also may have applications in other fields, including integrated circuit inspection and in manufacturing processes that require high accuracy.

For more information, contact Ann Hutchison of NASA Ames at 650-604-3039, or visit http://amesnews.arc.nasa.gov/releases/2001/01_16AR.html.



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For More Information Circle No. 572

Alternative Engineering:

How Virtual Reality and Simulation are Changing Design and Analysis

Interactive technology such as Fakespace's CAVE system allows designers to create models in numerous simulated environments. These engineers are working on an early model of the International Space Station.

When most people hear the phrase virtual reality (VR), they get ideas ranging from people wearing clunky headgear and strange garb, to a totally immersive environment with incredible levels of detail and interaction. In fact, virtual reality and simulation technology are both key components in a number of different areas, chief among them being manufacturing and design.

To understand what's being done with VR and simulation technology, one must understand that the differences between them are largely just a matter of interface. Both simulation and VR are tools that can be used for analyzing and testing materials, training people in numerous ways, and the design and implementation of new ideas and concepts.

The main distinction between the two is how the users operate the technology. VR often requires much more physical interaction on the user's part, while simulation typically is more passive.

Virtual reality is thought of as a very tactile process, incorporating gloves, joysticks, head-mounted displays, 3D stereo glasses, and rear-projection video screens and walls. Simulation involves visualization software with high-end graphics — often using 3D CAD models — operating on high-speed workstations. The two are used together by designers and engineers to create almost any type of artificial world imaginable. In these digital environments, most types of real-world situations, variables, and reactions can be duplicated.

For instance, an aerospace engineer could replicate a plane in flight and subject it to a myriad of stresses, including wind shears, thunderstorms, and equipment failure. By using this simulation, the engineer can see the results of tests and variables without using physical materials and possibly risking damage to person and property. In a more VR-oriented environment, the same engineer could design a program that allows a pilot to don a pair of 3D stereo glasses and use a joystick to "fly" that simulated plane. Then, when the plane is subjected to stresses, the pilot can react to them. This would provide data for both the pilot and the engineer to improve the design of the plane and its components.

The ultimate advantage of these technologies is truly collaborative design, engineering, and analysis — enabling groups of engineers to view and manipulate, in real time, a virtual object as easily as they could a physical object.

Pioneers in Reality

Fakespace Labs, a Mountain View, CA-based virtual reality company, began as a NASA spinoff originally contracted in the early 1990s by NASA's Ames Research Center (Moffett Field, CA) to develop a teleoperated motion platform for transmitting sounds and images from remote locations. The system, called Molly™, was combined with a BOOM™ stereo viewer and software to match a user's head motions in real time. The company, now with a second division — Fakespace Systems in Ontario, Canada — provides complete VR systems that allow users to create, display, express, and explore large, complex data sets as a shared experience.

Fakespace systems transition engineers and designers from the single-user, 2D workstation to collaborative, interactive 3D environments. Systems

such as the RAVE™ (Reconfigurable Advanced Visualization Environment) and CAVE® incorporate large-screen stereoscopic displays, flat walls, and immersive, walk-in theater environments.

"We are five years away from a consumer version of this type of work, although there are ways for consumers to get close to this level of detail now," said Jim Angelillo, vice president of strategic relations for Fakespace Systems. "Having a $200 graphics card, a pair of cheap passive glasses, and the right software will let you get on the right track." Fakespace got on the right track with Dassault Systemes about a year and a half ago when Dassault began integrating Fakespace's software capabilities into its CATIA CAD software. CATIA is the first application of any kind to have native immersive visualization capabilities built in.

According to Angelillo, while there are a number of different companies in the VR and simulation fields, they all provide very similar products and product types, which is why there is generally a focus on the same markets.

"One is manufacturing, and that covers the automotive industry, aerospace, and heavy equipment manufacturing," explained Angelillo. "Then there is the military/federal and education market. Government is by far the biggest user and that's true for any of the companies that sell VR."

NASA Ames has been a pioneer in the virtual reality area for decades, incorporating many cutting-edge technologies and developing new applications for those innovations, including medical imaging, telemedicine, and training. From space flight simulation to designing the shuttle's successor and its capabilities, VR plays a huge part in the work that NASA does. According to Francis Govers, Government Reality Center solutions manager for SGI (Mountain View, CA), his company has provided computers for a number of NASA centers, including a visualization system at Ames, and high-speed workstations that power a number of VR systems.

The most ambitious SGI/NASA virtual reality project is FutureFlight Central, located at Ames. The $10 million, two-story facility is designed to test — under realistic airport conditions — ways to solve potential air and ground traffic problems in a risk-free simulation environment. Twelve rear-projection video screens provide a 360-degree, full-scale, real-time simulation of an airport, allowing pilots, controllers, and other airport personnel to test out new technologies and operating techniques. The imaging system is powered by SGI workstations.

NASA's newest VR system, which was delivered earlier this year, is called the GRUVE (Glenn Reconfigurable User Interface and Virtual Reality Exploration) Lab at NASA's Glenn Research Center in Cleveland, OH. The lab features a RAVE that consists of three 8 x 8' rear-projection screens housed in moveable boxes, and powered by an SGI Onyx2 InfiniteReality2 system. The facility will display large amounts of data for engineers to look at small details, or to step back and see the big picture, according to Jay Horowitz, manager of the GRUVE Lab. The lab can be networked to other NASA centers to allow voice, data, and video communication among engineers at remote sites while working on a common project.

More Than Video Games

When companies started experimenting with the concept of creating computer programs to simulate stresses and other conditions in the early 80s, most of the focus was directed towards an industrial base of users. Now, as personal computers have become more and more powerful, simulation technology has become more accessible. And although video game development is one of the most prolific applications of virtual reality, other non-consumer uses of these

NASA's FutureFlight Central at Ames Research Center offers a two-story training facility. In this fully interactive simulated environment, controllers, pilots, and airport personnel can try out new techniques and technologies.

technologies are becoming much more widespread.

One of the sources from which visualization and VR technology originated was the science of creating maps through photogrammetry, according to Ian Matthews, director of marketing for StereoGraphics Corp., San Rafael, CA, which provides both 3D stereo eyewear and monitors for use in visualization systems. StereoGraphics' CrystalEyes3 is a wireless eyewear system that delivers stereoscopic 3D images in conjunction with compatible software and standard workstation displays.

"Major companies in the map-making business, such as ZI Imaging and LH Systems, use our technology to allow the people creating the maps to pick the elevations in order to digitize three-dimensional data," Matthews said.

Products like StereoGraphics' CrystalEyes3 allow designers to work on simulation projects on a smaller scale.

StereoGraphics is involved in more than just topography and medical research. Like many other VR and simulation companies, one of their primary focuses is the industrial design sector. The design and production of heavy equipment and automobiles is one of the largest markets for VR. That's not just because the technology offers a faster, simpler, and easier way to design these materials, but they also provide a means for testing them by constructing one physical model.

Across the various markets, the lack of a need for physical modeling and testing is one of the biggest advantages of simulation technology. Car companies can design and crash test a car thousands of times without damaging any physical materials. Bob Williams, development manager at ALGOR, Inc., a Pittsburgh, PA-based analysis software provider, points out that companies often begin virtual testing as simply a matter of cost savings. ALGOR specializes in both Finite Element Analysis (FEA) and Mechanical Event Simulation (MES) software. MES takes FEA models and generates their motion based on physics-based inputs and calculates stresses, displacement, and general behavior that a given part would demonstrate in the real world.

"Because of the expense and the time involved with physical testing, you want to try and iron out as many things as possible up front before you do any physical prototyping," said Williams.

Another software company, ERDAS of Atlanta, GA, provides geographic imaging solutions, such as IMAGINE Professional, which is designed to help organizations visualize, manipulate, analyze, measure, and integrate any type of geographic imagery and geospatial information into 2D and 3D environments.

Part of what makes VR and simulation technology so appealing to designers and manufacturers alike is the ease with which it can incorporate existing designs. Most design work for manufacturing is done with some form of 2D or 3D CAD software. Since virtually all simulation systems operate with the OpenGL graphics standard, importing a CAD model and applying physics to it — such as putting a car frame model into a wet road simulation — is practical and cost


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effective. While engineers may have to learn how to operate the simulation technology itself, they still have other familiar design tools at their disposal.

Tools of the Trade

According to SGI's Govers, having the right equipment is the first and most important step in running a VR system. "In order to do large-scale 3D graphics," he said, "first of all, you have to have a fast computer. Second of all, you have to have the ability to bring data in and out of that computer very quickly and at very high bandwidth."

Other high-end computer suppliers, in addition to SGI, are working to make super-fast workstations more accessible. Hewlett-Packard offers the HP Visualize Center, a fully immersive visualization system powered by three synchronized HP j6000 workstations with Visualize-fx10pro graphics. The machines work in tandem with large-scale 3D stereographic display systems and OpenGL software to bring products to life in a seamless, wide-field display.

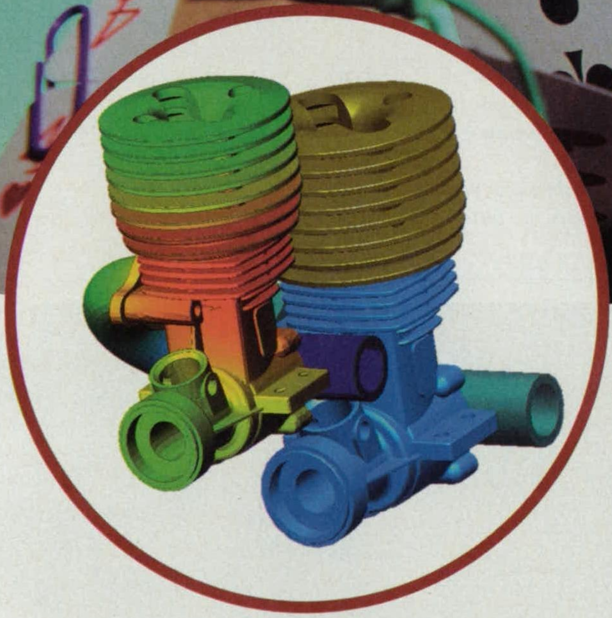
The HP Visualize workgroup solution is a smaller, desktop version built around a single dual-processor HP j5600 workstation. The workgroup drives seamless displays that can be deployed right into the engineering workspace or on the engineer's desk.

Connecting the user to the equipment is just as important as having the right equipment. One of the constant themes in VR and simulation technology is ease of use. As markets and uses for the technology continue to broaden, the people who are using it aren't necessarily trained to understand simulation coding and physics. Williams stressed the fact that the human part of the equation is becoming more and more vital as the field advances.

"It is one thing to provide a tool that can do all these sorts of simulations," said Williams. "It is another thing to provide a tool that makes it easy to do this. We've also spent a lot of time focused on making the set-up and just building on these models, utilizing these models, and also looking at results and how they behave."

By focusing on how everything works, Williams explained that it makes it easier to understand how to make the systems more intuitive. For a company like ALGOR, which focuses on finite element analysis and mechanical event simulation, the goal is making sure users can understand what stresses they are applying to their models.

For a company like SGI, which offers a broader range of simulations, the need for ease of use is much more about how



This digital environment, created by ERDAS' IMAGINE VirtualGIS software, is an example of the level of detail and scope that can be obtained using VR and simulation technology.

the people respond to what they are seeing on screen.

"The term I like to use is increasing the human bandwidth," says Govers. "We want to be able to get information to people quicker and make it easier to understand and to make it easier to get from where it's data to where it's information. Make it more of a natural interface."

The human aspect of virtual reality is what will drive the market from where it is now — more affordable and easier to use than it was five years ago, but still not perfected. "The thing that virtual reality requires is more and more of the senses being able to interact with the computer environment," said StereoGraphics' Matthews. "Today, the primary senses that are being exercised are vision and feel."

Feeling that you're actually present in a computer-generated environment takes more than just cool imagery. It's all in the details. Enhanced 3D graphics software, high-resolution projection screens, lightweight stereo eyewear, and super-fast computers all will continue to evolve and result in more realistic virtual environments for collaborative engineering.

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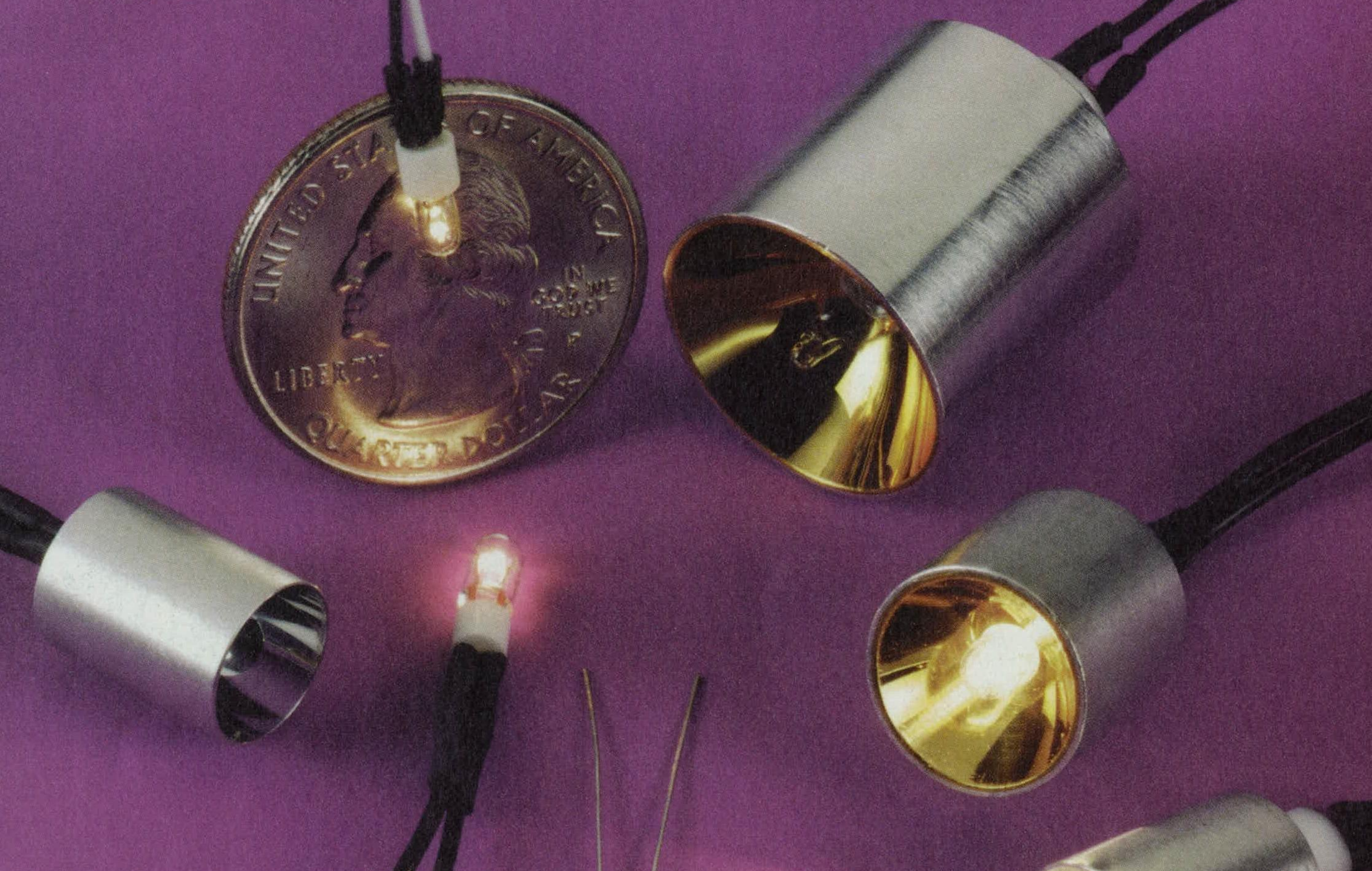


Cover photo courtesy of Gilway Technical Lamp Inc.

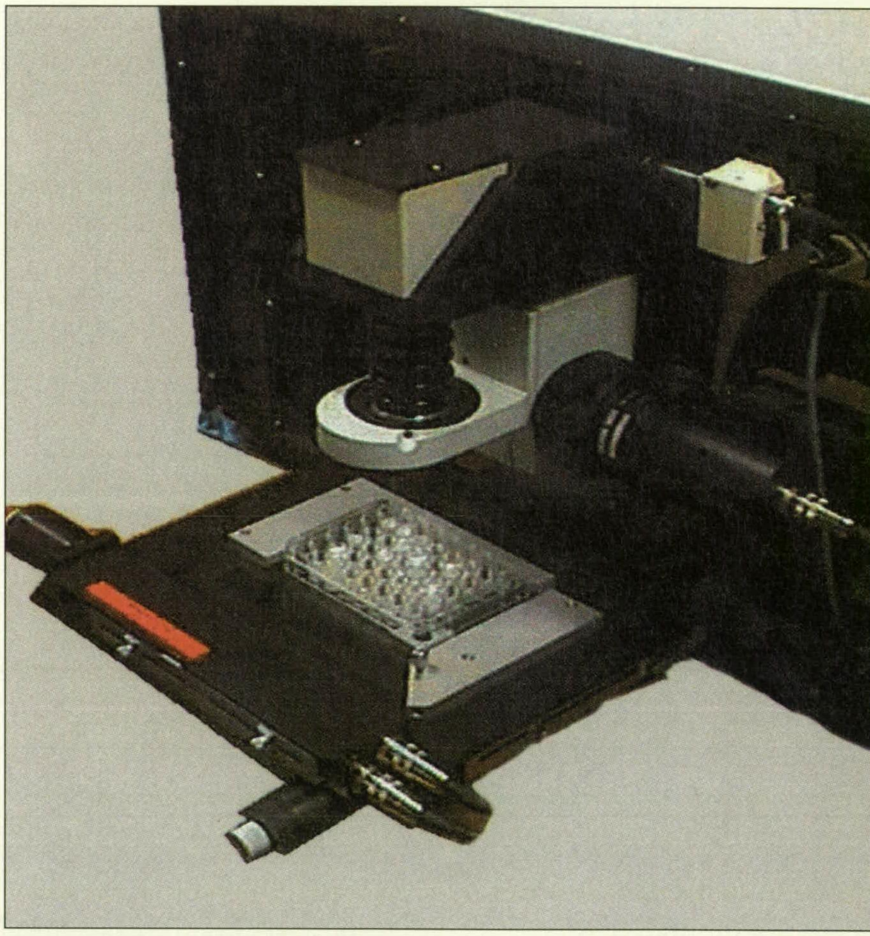
The Many Facets of Raman Spectroscopy

A mature analytical technique finds new means and applications.

As a tool for determining the chemical content of a sample, or some other property, spectroscopy has been around a long time. But still the industry continues to improve the techniques and the equipment, making life easier – and analysis times shorter – for the researcher in the laboratory. And as more powerful and more compact lasers are developed for the needed excitation wavelengths, mature techniques such as Raman spectroscopy gain new adherents.

According to Thermo Nicolet Instruments of Madison, WI, the spur that made Raman spectroscopy a routine analytical method was the development of Fourier transform detection techniques. Fourier transform IR (FT-IR) instruments measure the interaction of infrared radiation with samples. Both the absorption frequencies and the absorption intensity of the radiation are recorded. The frequency data is used to determine the sample's identity, and the intensity information the concentration of the material or materials of interest.

In FT-IR Raman spectroscopy the 2D spectral plot shows Raman shift emission along the x-axis rather than intensity, as in competing methods. When near-IR light strikes it, the sample scatters Raman radiation, at slightly longer (Stokes lines) or slightly shorter (anti-Stokes lines) wavelengths than that of the laser that causes the excitation. After the scattered light is detected, the computer, using the Fourier transform process, converts the data into a spectrum. Among the experiments and analytical methods now using FT-Raman are monitoring real-time polymerization reactions at controlled temperatures and using fiber optic probes to identify nuclear waste materials remotely.



Jobin Yvon's Raman Multiwell Analyzer

Thermo Nicolet points to research and development of new products, quality control of manufactured goods and incoming materials, forensic analysis, environmental testing, and other applications where FT-IR analysis proves valuable. The company says FT-Raman has particular relevance to measuring polymers, pharmaceuticals, aqueous materials, biological substances, hazardous and explosive materials, drugs, inorganic materials, and reaction monitoring.

Top of the Line

Thermo Nicolet offers a broad range of spectrometers and other spectroscopic instruments. At what it calls the "pinnacle" of its "Pyramid of Power" is the Nexus 870. The device includes all of the standard features of its Nexus line of

research FT-IR spectrometers, combined with other advanced research capabilities. These include phase modulation step-scan spectroscopy, for photoacoustic depth profiling; dynamic polymer stretching step-scan; time-resolved step-scan spectroscopy; and amplitude modulation step-scan spectroscopy. Other capabilities are dual-channel collection for PM-IRRAS, advanced scanning velocities for rapid scan and slow scan, and extended spectral range (from 25,000 to 20 cm^{-1}), and hyphenated techniques such as advanced infrared microscopy and FT-Raman spectroscopy.

Among FT-Raman systems, Thermo Nicolet offers the FT-Raman 960, which the company says was designed for corporate or academic researchers who want the optimum in FT-Raman performance. It uses gold-coated reflective optics throughout its high-throughput optical design. The 960 offers the ability to search unknown spectra against several commercial libraries. It allows data collection with no sample preparation, and collection from aqueous solutions without strong interference from the water content. It also allows nondestructive sampling through thin plastic bags, blister packs, or glass bottles without the need to remove or have contact with the samples inside.

From another leading supplier of spectroscopic systems, Kaiser Optical Systems, of Ann Arbor, MI, a Rockwell Collins company, comes a wide range of instruments providing Raman or other kinds of spectroscopic techniques. Prominent among these is the HoloLab Series 5000 modular Raman spectrometer. Kaiser says that its modular architecture provides experimental versatility and stability, yet allows for future expansion or upgrading. At its heart is Kaiser's axial transmissive imaging spectrograph design, which combines fast f/1.8 optics with HoloPlex™ transmission grating technology. This grating, and the instrument's multichannel CCD array detector, yields spectral coverage from 100 to 4400 cm^{-1} with 532-nm excitation without aperture sharing or scanning. Kaiser Optical says this means reduced data acquisition times per sample.

The Series 5000 spectrometer can be outfitted with the Mark II holographic filtered probehead (HFPH), which Kaiser says will supply high signal-to-background measurements. This probehead uses a single fiber for excitation and another for collection. Standard telecommunications fiber diameters (less than 100 microns) result in increased mechanical stability.

Kaiser says that, for process equipment, single fibers reduce the cost of long runs of multiple collection fibers, and also permit multichannel operation on a single spectrograph. Noncontact optics with working distances of 0.1 in. to 17 in. can measure through windows or bottles, or simply at a safe distance from a sample. Immersion and insertion optics use single, double, or triple window designs to allow safe, direct installation into reaction vessels or process streams.

Instant Collection

The HoloLab Series 5000 Raman integrated system is also based on Kaiser's axial transmissive imaging spectrograph design, featuring f/1.8 optics and HoloPlex transmission grating technology. The company says that the entire Raman spectrum is collected instantaneously at high resolution by optically folding the scattered Raman photons onto a large-format multichannel CCD detector. Options include a Raman microscope, a remote filtered probehead, and a Class 1 sampling compartment, as well as three excitation wavelengths (532, 633, or 785 nm). Alternative gratings, cameras, and laser sources are available. Kaiser says Windows®-based HoloGRAMS™ data acquisition and GRAMS/32/®C spectral analysis software makes Raman data easily acquired and quickly analyzed.

Also incorporating the HoloPlex grating technology is Kaiser's line of RamanRxn2 analyzers, which, like the HoloLab Series 5000, collect the entire Raman spectrum instantaneously at high resolution. This enables the collection of wavelengths of chemically changing samples such as polymerizations, curing, and bubbling solutions or species with widely separated analytical bands of interest. Kaiser says more accurate quantitative analysis results, and that the modular instrument design and fiber optic coupling provide robust performance and analyzer stability.

Kaiser's entries in the telecommunications arena are the UltraSpec-C 160 and UltraSpec-L160 for DWDM network monitoring applications. The C-160 has the range and resolution necessary for characterization of the telecommunications C-band spectrum at 50-GHz channel spacing, while the L-160 extends that to the L-band spectrum. Expanding on holographic optics deployed in Raman spectrographs and military avionics, the patent-pending UltraSpec grating/prism structure uses a Volume Phase Holographic (VPH™) transmission grating recorded in dichromated gelatin and sealed between two precision prisms. Kaiser says the expanded beam footprint on the grating, much larger than the beam cross-section, results in a combination of high dispersion and high resolution in a very compact package.

High-Throughput Screening

According to sources at Jobin Yvon, the spectroscopy arm of the Horiba group, based in Edison, NJ, the latest approach in analytical technology is high-throughput screening. This technique has become important in the pharmaceutical industry and in life-science laboratories, where it is used in screening of drug design and analysis of batch production. JY Horiba says the new Raman Multiwell Analyzer was specifically constructed for use in the manufacturing environment. High-throughput applications mean the sample reaction process is undertaken in multiwell plates, and this instrument, based on JY Horiba's analytical LabRAM system, has been adapted for use as a fully automated multiwell analyzer. The company says its new optical designs mean a single multiwell plate – the standard is 12 × 8 – can be analyzed in a matter of seconds. Additional features include a dedicated long-travel autofocus system to compensate for different well filling heights; two selectable gratings inside the spectrometer, allowing either high-resolution mode or quick analysis with full spectral coverage; and full integration of different lasers.

Get connected with the companies mentioned in this article:

Thermo Nicolet Instruments Corp.
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PHOTONICS *file*

Recent photonics briefs published in NASA Tech Briefs

Many photonics-related briefs from NASA's field center laboratories appear in *NASA Tech Briefs* rather than in the *Photonics Tech Briefs* supplement. Listed here are some from issues of *NASA Tech Briefs* just past, edited for brevity and indexed with reference to original publication and the availability of a Technical Support Package on *Photonics Tech Briefs'* web site.

NASA Tech Briefs February 2001, page 42

Optical Measurement of Temperatures in Muscles and Tendons (NPO-20562)

Miniature fiber-optic-coupled sensors based on optically excited, self-resonant microbeams have been proposed by a Jet Propulsion Laboratory team for measuring temperatures within muscle fesicles and tendons. The proposed sensors could be used in medical and biological research on humans and other animals. Each sensor would be made of electrically nonconductive materials that are chemically and galvanically inert with respect to living tissue. Typical sensor dimensions would be about 0.5 by 0.5 by 0.1 mm. These dimensions are suitable for surgical implantation; they are also comparable to diameters of cores of multimode optical fibers, making the sensors amenable to fiber-optic coupling.

For further information, access the Technical Support Package (TSP) ***free on-line at www.ptbmagazine.com*** *under the Test and Measurement category.*

NASA Tech Briefs April 2001, page 34

High-Speed Image Compression via Optical Transformation (NPO-20638)

A method of compressing image data proposed by a Jet Propulsion Laboratory scientist would exploit the capability of a converging lens to generate the Fourier transform of an image by purely optical means, in much less time than is needed to compute the discrete Fourier transform of a sampled image by use of digital electronic circuits. Because the transform, of whatever kind, is the most computation-intensive part of almost any electronic image-compression scheme, the speedup afforded by this method could make the difference between success and failure in applications in which data must be compressed at high throughput rates.

For further information, access the Technical Support Package (TSP) ***free online at www.ptbmagazine.com*** *under the Physical Sciences category.*

NASA Tech Briefs April 2001, page 37

Algorithms for Recognition of Objects in Color Stereo Images (NPO-20754)

A researcher at Jet Propulsion Laboratory has developed algorithms to enable a robotic vision system to recognize, in real time (at a rate between 0.5 and 2 frames per second), known objects lying on the ground. Raw data from a pair of color stereoscopic images are subjected to rapid preliminary processing to detect candidate locations to be more thoroughly examined. Once the candidates have been detected, additional computations are performed to reduce false alarms, reason about the remaining available image data, and make a final decision about each candidate.

For further information, access the Technical Support Package (TS) ***free online at www.ptbmagazine.com*** *under the Information Sciences category.*

NASA Tech Briefs April 2001, page 38

Infrastructure Software for Mining Image Data Bases (NPO-20921)

A team at Jet Propulsion Laboratory has developed Diamond Eye, a computer program that enables a user equipped with only a personal computer, web-browser software, and a network connection to analyze large collections of scientific image data. The system is based on a distributed applet/server architecture that provides platform-independent access to image mining services. The computational engine provides parallel execution of the most demanding parts of the data-mining task: image processing, object recognition, and querying-by-content operations. Diamond Eye is currently being used to locate and catalog geological objects in large image collections, but the design provides infrastructure for a range of scientific data-mining applications.

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Pyramid-Shape Light Coupler for Multi-Quantum-Well Photodetectors

Light-coupling efficiency should exceed that of corrugated couplers.

NASA's Jet Propulsion Laboratory, Pasadena, California

Wavelength-independent light couplers in the form of planar arrays of pyramids have been proposed for use on multiple-quantum-well infrared photodetectors. Wavelength-independent light couplers are needed for focal-plane arrays of QWIPs designed to operate in multiple and/or broad wavelength bands. In the proposed pyramid light couplers, wavelength independence would be achieved by sizing and shaping the pyramids to exploit reflections and refractions that, to a first approximation, depend on geometry only.

Because of a quantum selection rule related to polarizations, a quantum-well infrared photodetector (QWIP) does not absorb light incident normal to the planes that make the quantum-well layers: The rule arises because the quantum wells can absorb only light polarized perpendicularly to the planes that bound the quantum-well layers, whereas normally incident light is polarized parallel to these planes.

Most commonly, a QWIP device is fabricated so that the planes that bound the quantum-well layers are parallel to the broad outermost faces of the device; therefore, by virtue of this quantum mechanical selection rule, light incident normal to these faces is not detected. A light coupler is needed to redirect incident light so that it traverses the QWIP layers in a direction that includes at least some vector component parallel to the planes that make the quantum wells. In other words, the function of a light coupler on a QWIP is to redirect normally incident light to oblique incidence.

Heretofore, the only wavelength-independent light couplers for QWIPs have been corrugated ones – parallel ridges and valleys. A corrugated light coupler can redirect normally incident light in a direction with vector component perpendicular, but not parallel, to the ridge lines. On the other hand, a pyramidal light coupler could redirect normally incident light along directions with vector along both mutually perpendicular axes in a plane parallel to the quantum-well surfaces; as a result, light should be coupled more efficiently by a pyramidal than by a corrugated coupler.

Corrugated light couplers are fabricated by wet chemical etching that is selective with respect to crystallographic planes. Consequently, a corrugated light coupler can be oriented only parallel to one crystallographic plane; it is not possible to fabricate two crossed, superimposed corrugated light couplers by wet chemical etching to obtain a pyramidal light coupler.

The proposed pyramidal light couplers would be fabricated by poly(methy methacrylate)- (PMMA)-pattern-transfer techniques: In preparation for fabricating an array of pyramids on a GaAs-based QWIP, PMMA would be spun over the surface of the GaAs epitaxial material. A pattern corresponding to the array of pyramids would be formed in the PMMA by electron-beam lithography and development of the electron-beam-exposed PMMA. Finally, the pattern would be transferred to the epitaxial GaAs by reactive-ion etching in a plasma generated by electron cyclotron resonance.

This work was done by Sarath Gunapala, Sumith Bandara, and John K. Liu of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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Refer to NPO-20521, volume and number of this NASA Tech Briefs *issue, and the page number.*

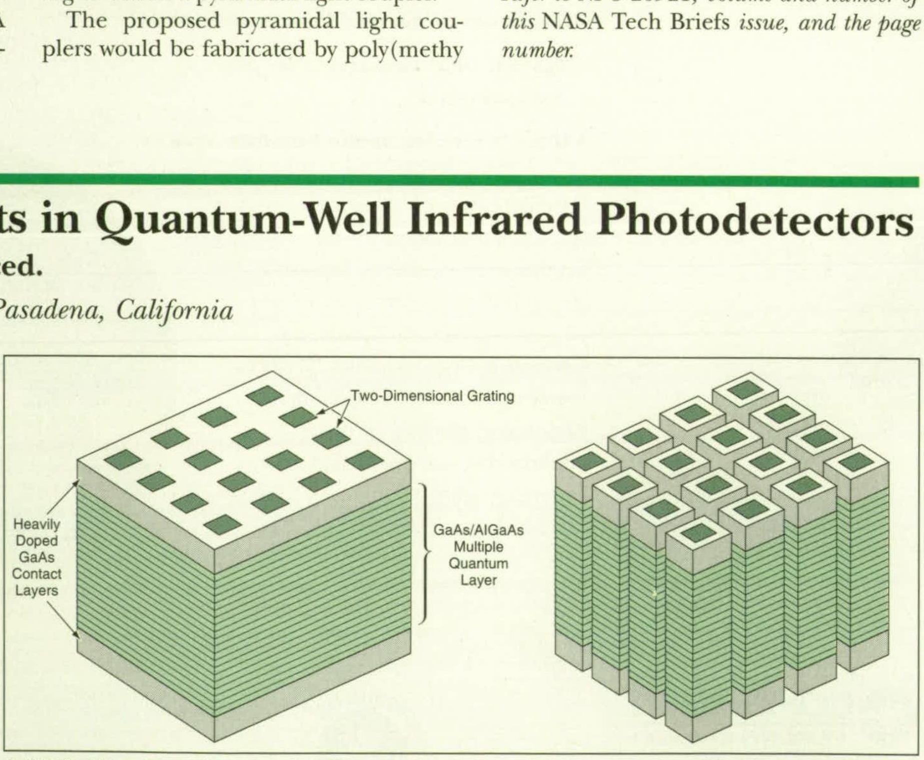
Noise-Reducing Slots in Quantum-Well Infrared Photodetectors

Dark currents would be reduced.

NASA's Jet Propulsion Laboratory, Pasadena, California

Quantum-well infrared photodetectors (QWIPs) that include two-dimensional surface grating light couplers would be modified, according to a proposal to incorporate crossed slots. It should be possible to increase signal-to-noise ratios by suitable positioning and dimensioning of the slots, as explained below.

The figure depicts part of a typical GaAs/AlGaAs QWIP with a two-dimensional surface grating light coupler. The need for, and function of, a light coupler on a QWIP is described in the preceding article. In the case of a two-dimensional surface



A QWIP With a Two-Dimensional Surface Grating Light Coupler would be modified by incorporation of slots in regions where little light is absorbed.

grating light coupler, there is an important effect incidental to the basic light-coupler function; the absorption of light inside the QWIP becomes concentrated into columns under the surface grating.

Because little or no light is absorbed in regions between the columns, material could be removed from these regions without reducing photocurrent much, if at all. This leads to the concept of slots. The positions and dimensions of the slots would be chosen to correspond to the low-absorption regions.

While the incorporation of slots would exert little or no effect on photocurrent, it would significantly affect noise. The dark current of a QWIP is proportional to its effective area. In the presence of slots, the effective area would be the cross-sectional area of the columns between the slots. In a typical case, this remaining area would be only one-fourth the original area; consequently, the dark current of the slotted QWIP would be only one-fourth the dark current of the unslotted QWIP. Inasmuch as the noise current of a QWIP is proportional to the square root of its dark current, the noise current of the slotted QWIP would be reduced to half that of the unslotted QWIP, resulting in a signal-to-noise ratio twice that of the unslotted QWIP at any wavelength and temperature.

Another anticipated benefit of slotting would be an increase in the fraction of incident light converted to polarization perpendicular to the planes bounding the quantum wells and thus an increase in light-coupling efficiency. The estimated net effect of slotting would be an enhancement of detectivity by a factor of 3 to 4.

This work was done by Sarath Gunapala, Sumith Bandara, John K. Liu, and Daniel Wilson of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

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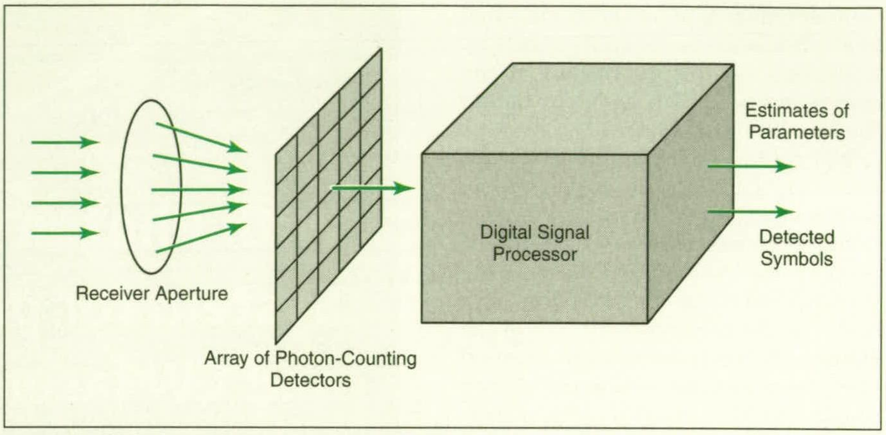
Refer to NPO-20518, volume and number of this NASA Tech Briefs *issue, and the page number.*

Adaptive Focal-Plane Detector Arrays for Optical Communications

Degradation of signals by atmospheric turbulence would be reduced.

NASA's Jet Propulsion Laboratory, Pasadena, California



An **Array of Photon-Counting Detectors** would capture atmospheric-turbulence-induced random excursions of a received signal from a central, diffraction-limited focal spot. The digital signal processor would execute an algorithm that would weight the contributions of detectors in such a way as to reduce the relative contribution of background radiation.

Arrays of photon-counting detectors and associated digital signal processors have been proposed for receivers in optical communication systems in which the optical signals propagate through the atmosphere and are relatively weak upon reception. The digital signal processor would execute algorithms that adapt the overall responses of the receivers to the temporally varying photon counts of the individual detectors in such a manner as to reduce the deleterious effect of atmospheric turbulence.

In a system to which this proposal applies, the receiver would include a diffraction-limited telescope with an aperture diameter on the order of 1 to 10 m and a focal length on the order of twice the aperture diameter, and would be used to detect a signal at a wavelength around 1 μm. In the absence of atmospheric turbulence, most of the received signal power could be focused onto a single focal-plane detector no larger than the diffraction-limited spot size, and background radiation from directions other than that of the signal source would be effectively spatially filtered out.

In the presence of atmospheric turbulence, the phase of the optical signal arriving at a telescope becomes uncorrelated over distances greater than a coherence length that ranges from approximately 20 cm at night to as little as 2 to 4 cm during the day. The result is that the signal power is spread over a spot much wider than the diffraction-limited spot in the focal-plane, and the portion of signal power received at a given point in this wider spot tends to fluctuate on a time scale of about 10 to 100 ms. Hence, in order to capture most of the received signal power, it would be necessary to use a correspondingly larger-diameter detector, which, because of its greater field-of-view, would also capture more of the undesired background radiation.

In a system according to the proposal, a single large detector would be replaced by an array of smaller detectors, the photon-counting outputs of which would be fed to a digital signal processor (see figure). In the processor, the temporally varying photon counts from the detectors would be effectively weighted and combined by algorithms that assign greater weights to detectors receiving greater signal powers; thus, the contribution of undesired background radiation from detectors receiving less signal power would be reduced, the net effect being that the overall signal-to-noise ratio of the received signal is increased.

The detection algorithms have been formulated specifically for a communication system that uses M-ary pulse-position modulation in which the receiver attempts to determine which of M possible symbols has been received by observing the photon counts accumulated during each of the M time slots of a symbol period. It is assumed that the receiver is synchronized and, hence, "knows" the beginning and ending times of each symbol period as well as the time of arrival of each detected photon, and that these times and the associated photon counts can be stored for the limited amount of time needed for processing. It is also assumed that the photon-count outputs of the detectors are Poisson-distributed in time.

One of the algorithms utilizes continuous weighting of the counts from the individual detectors to implement an optimum array-detector receiver. However, this algorithm is not practical because the computational burden quickly becomes excessive as the number of detectors increases.

In the alternative simplified algorithm, continuous weighting is replaced by hard decisions on the selection of detectors from which the counts are to be considered at a given instant. This algorithm would implement a computationally simpler, suboptimum array-detector receiver. Computational simulations for representative cases have shown that the performance of the simpler suboptimum algorithm is almost equal to that of the more complex optimum algorithm, and that the improvement in performance over a single detector of diffraction-limited size would be equivalent to an increase in signal strength of about 5 dB under realistic operating conditions.

This work was done by Victor Vilnrotter and Meera Srinivasan of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components & Systems category.*

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Refer to NPO-21041, volume and number of this NASA Tech Briefs *issue, and the page number.*

Two-Axis Scanning Mirror in a Small Package

This compact, lightweight assembly enables scanning with high resolution and minimal backlash.

NASA's Jet Propulsion Laboratory, Pasadena, California

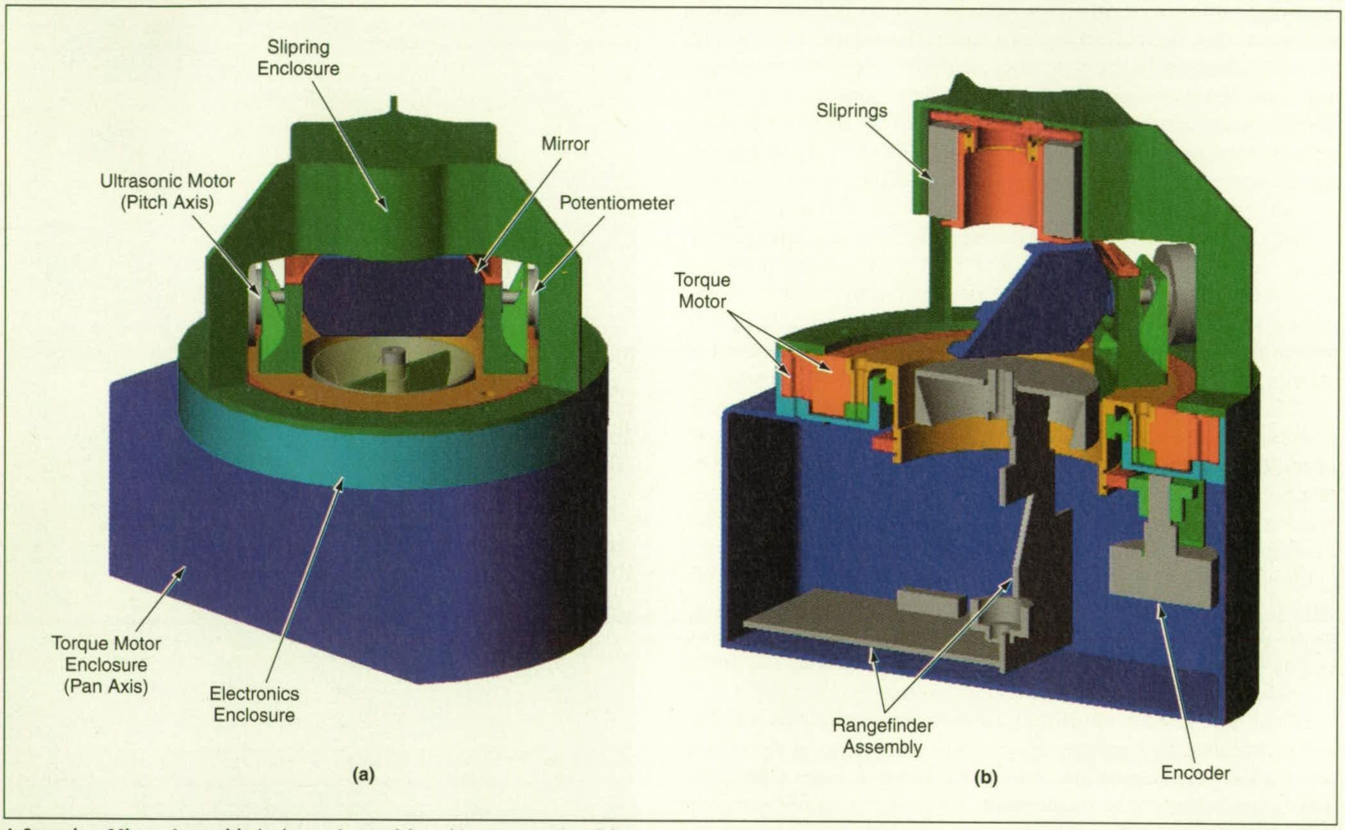
A compact two-axis scanning-mirror assembly (see figure) has been developed for use as part of a laser rangefinder on a robotic vehicle. The assembly is designed to enable scanning of the laser beam throughout the space surrounding the vehicle for three-dimensional mapping of objects in the vicinity.

Two-axis scanning-mirror assemblies of prior design exhibit two notable weaknesses, one being actuator backlash caused by gear-train slop. The present assembly contains direct-drive actuators that exhibit little or no backlash; as a result, the precision and resolution of beam positioning is limited only by the resolution of a feedback subsystem that is part of a control system operated in conjunction with the assembly. Moreover, because no gear trains are included, the number of moving parts is reduced and thus reliability is increased, relative to assemblies of prior design. The other notable weakness of prior designs is inability to pan continuously; the present assembly includes sliprings, which enable continuous panning.

The assembly includes a base that consists of a housing for the electronic drive circuitry and for the laser system of the rangefinder. Built into the top of the housing is the stator of a pan motor. An integral part of the stator mount is a domelike structure that supports the upper end of a pan rotor subassembly. An upper support bearing and the stator of a slipring subassembly lie within the domelike structure near its top.

The pan rotor subassembly consists of the rotor of the pan motor and an arch that is part of a tilt subassembly. The arch is tipped by the rotor of the slipring subassembly. The arch spans the open bore of the rotor of the pan motor. Between the sides of the arch is the mirror, supported by a bearing on each end of a tilt axle. The mirror is driven in tilt by an ultrasonic motor (USM) on one end of the tilt axle.

The overall design was driven by the desire to build the smallest unit possible for a given mirror size [≈1.4 in. (≈3.6 cm) high by ≈2 in. (≈5.1 cm) wide] while making it possible to orient the mirror as precisely as practicable. To this end, a through-bore motor was chosen as the pan actuator. The open bore makes it possible to place part of the laser circuitry within the motor envelope, saving volume. The direct-drive, through-bore pan motor is capable of continuous pan motion and of angular positioning with relatively high resolution. Also, the direct-drive design eliminates mass and volume that would otherwise be associated with a gear train.



A **Scanning-Mirror Assembly** is shown intact (a) and in cross section (b).

One important advantage of a USM is passive braking; when power is not applied, it holds its position. Hence, the use of the USM as the direct driver on the tilt axis also eliminates mass and volume that would otherwise have been associated with an external brake that would have to be put on a gear train. In addition, a USM weighs less than does a conventional electric motor.

This work was done by Brett Kennedy of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation category.*
NPO-20904

Hot Dielectrics as Light Sources for TPV Devices and Lasers

Wavelength-selective emitters are combined with optical waveguides to form superemissive light pipes.

John H. Glenn Research Center, Cleveland, Ohio

Experiments have demonstrated the feasibility of using flame-heated refractory dielectric solid bodies as wavelength-selective sources of light for special applications; in particular, for powering thermophotovoltaic (TPV) devices and for pumping lasers. A refractory dielectric material suitable for this purpose is one that, when heated by a flame, emits intense light with a spectral peak or peaks at one or more visible and/or infrared wavelengths. For a given laser or TPV application, one would choose such a material with an emission peak or peaks to match the corresponding laser absorption or TPV response peak(s). The emissive material can be in the form of a mantle or a felt, or it can be one of the chemical constituents of a solid crystal. To increase the effectiveness of a light source of this type, one can join a crystalline rod containing the emissive material with another rod (which serves as an optical waveguide) to form a device called a "superemissive light pipe" (SELP).

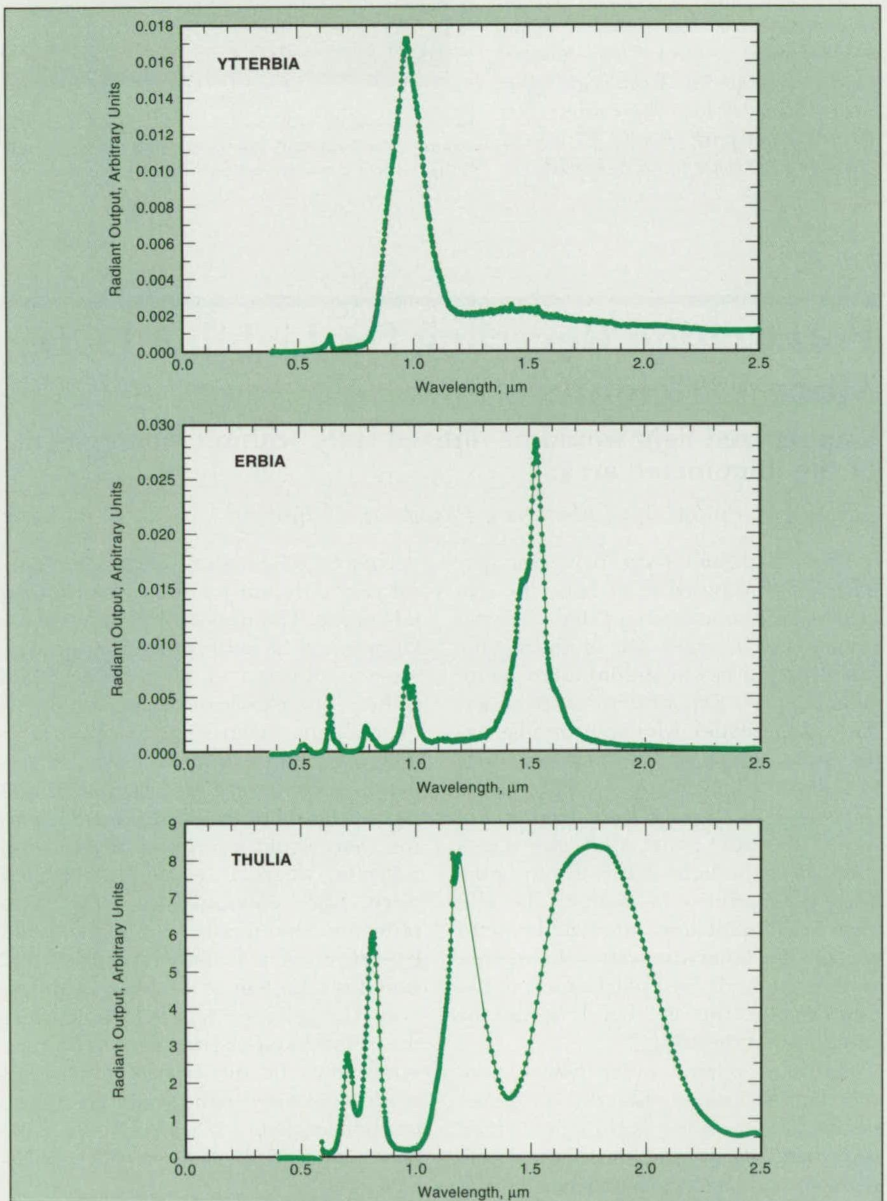


Figure 1. **Emission Spectra** of flame-heated mantles of three materials contain peaks that can be matched to absorption peaks of other materials to achieve transfer of energy in various applications.

In one set of experiments, ytterbia, erbia, and thulia were tested as candidate emissive materials in an effort to match the absorption peak of Nd^{3+} in neodymium: yttrium aluminum garnet (Nd:YAG) lasers and to match the photovoltaic response peaks of Si and GaSb TPV devices. Figure 1 shows the measured emission spectra of mantles of these materials heated by propane flames. Thulia could be chosen for pumping Nd:YAG lasers because its spectral peak at a wavelength of 818 nm lies in the absorption band (790 to 890 nm) of Nd^{3+}. The erbia spectrum shows only weak emission in the Nd^{3+} absorption band but is well matched to the spectral response of GaSb devices.

SELPs made of various material combinations were tested in another set of experiments. For example, Figure 2 depicts a test setup for measuring the output of a GaSb photovoltaic cell under illumination from a SELP that comprised an emissive crystalline rod of erbium aluminum garnet ($Er_3Al_5O_{12}$, also known as "ErAG") bonded to a YAG light pipe. In one experiment in which the ErAG emitter was heated to an estimated temperature of 1,350 °C by torches burning stabilized methacetylene propadiene (commonly called "MAPP gas"), the photovoltaic-power density was found to be 1.56 W/cm², corresponding to a photon-to-electron conversion efficiency of 29 percent. It has been estimated that if the emitter temperature were raised into the range of 1,500 to 1,600 °C, and if the conversion efficiency were to remain the same, then the photovoltaic-power density would rise to about 5 W/cm².

This work was done by L. G. DeShazer, A. S. Kushch, and K. C. Chen of Quantum Group, Inc., for **Glenn Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

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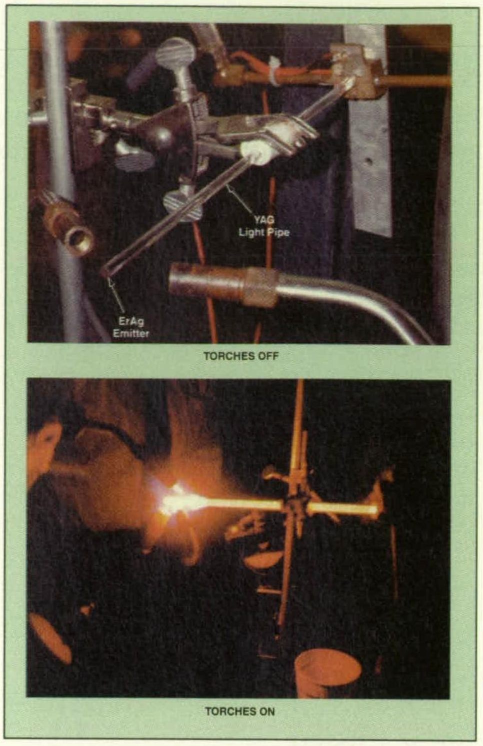

Figure 2. An **ErAG/YAG SELP** was tested for use in radiantly supplying power to a GaSb photovoltaic cell.

Polarization Recycling for Lighting LCDs More Efficiently

Unpolarized light would be utilized fully, without enlargement of the illuminated area.

NASA's Jet Propulsion Laboratory, Pasadena, California

Two polarization-recycling techniques have been proposed to increase the efficiency of illumination of liquid-crystal display (LCD) panels. The motivation for this proposal lies in the inherent inefficiency of an LCD panel: For proper operation, illumination with polarized light is necessary, but a typical lamp generates unpolarized light. If one simply passes the lamp light through a polarizer on the way to the LCD panel, then one wastes the half of the light that is in the undesired polarization. To increase the efficiency of illumination, one would have to recycle the otherwise wasted light, converting the undesired polarization to the desired one; this is what is meant by "polarization recycling."

Unlike a related older polarization-recycling technique, the two proposed polarization-recycling techniques would not enlarge the cross section of the illuminating beam. (Such enlargement is a disadvantage in a typical application in which one seeks to illuminate a small panel.)

Figure 1 schematically depicts the optical configuration for the first proposed technique. The unpolarized light from a lamp would be concentrated by a reflector and directed to a polarizing beam splitter. The p-polarized light would pass through the beam splitter, while the s-polarized light would be reflected perpendicularly toward an LCD panel. The p-polarized light would strike a flat mirror, then would travel back to the lamp reflector, where it would be reflected twice. After emerging from the lamp reflector, the p-polarized light would pass through a half-wave retarder that would occupy half of the beam cross section. The half-wave retarder would cause the reflected p-polarized light to become s-polarized. In the beam splitter, this newly s-polarized light would be reflected perpendicularly toward the LCD panel, along with the originally s-polarized light.

For the portion of unpolarized lamp light that would hit the half-wave

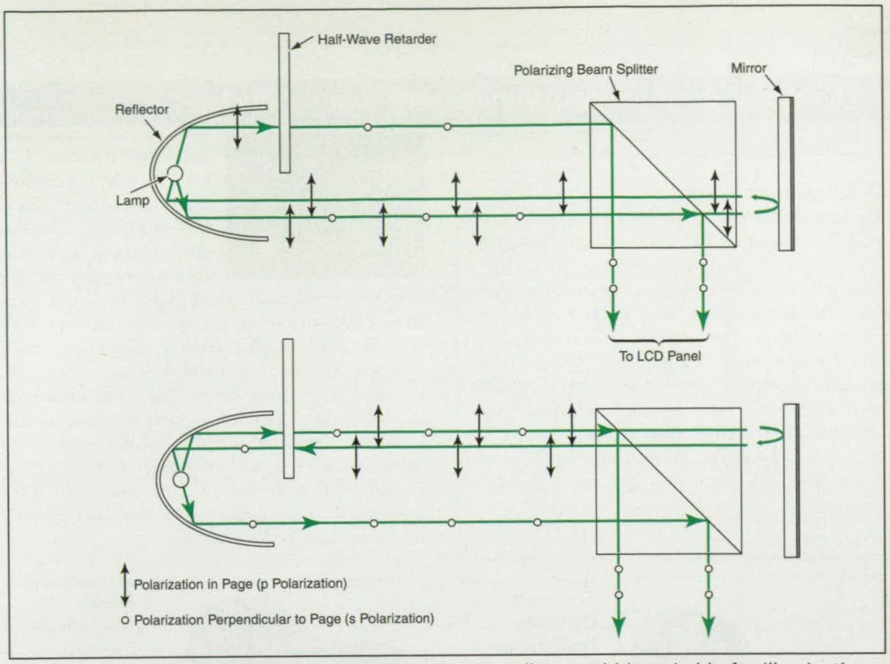

Figure 1. This **Optical Configuration for Polarization Recycling** would be suitable for illuminating a small panel facing perpendicularly to the optical axis of a lamp reflector.

retarder first, the end result would be the same, though the sequence of events would differ: After passing through the half-wave retarder, the initially unpolarized light would remain unpolarized until it reached the polarizing beam splitter. The p-polarized subpart of this part of the light would pass through the beam splitter, while the s-polarized subpart would be reflected perpendicularly toward the LCD panel. The p-polarized light would strike the flat mirror and would go back through the half-wave retarder, which would convert it to s-polarized light. Continuing along its path, this portion of s-polarized light would be reflected twice by the lamp reflector, and would finally be reflected perpendicularly, by the beam splitter, toward the LCD panel.

Figure 2 schematically depicts the configuration for the second proposed technique. Light from a lamp would reach a reflective polarizer; the p-polarized light would pass through to the LCD panel, while the s-polarized light would be reflected. The reflected s-polarized light would pass through a quarter-wave retarder, becoming circularly polarized. The circularly polarized light would be reflected by a flat mirror and would go back through the quarter-wave retarder, which would cause this light to become p-polarized, as needed to join the originally p-polarized light in illuminating the LCD panel.

This work was done by Yu Wang of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

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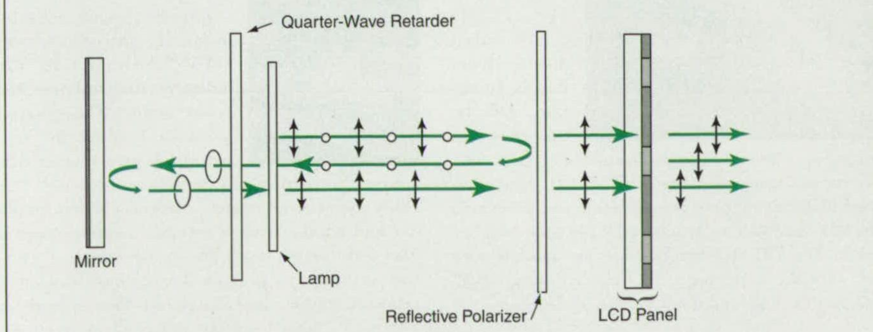

Figure 2. This **Alternative Optical Configuration** for polarization recycling could be suitable for illuminating a panel (e.g., a notebook-computer LCD panel) that would be on a direct optical path from a lamp.

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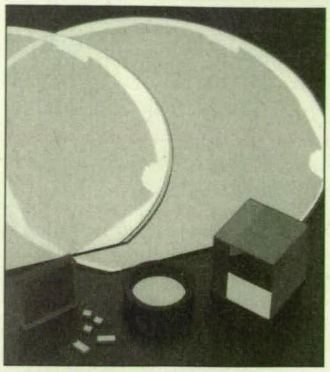
Product of the Month

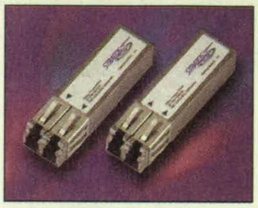


Unique Polarizing Technology

Meadowlark Optics, Frederick, CO, has formed an alliance with Moxtek, Urem, UT, to introduce the new VersaLight™ polarizer that draws on the latter's unique polarizing technology. Meadowlark says that VersaLight provides the broadest wavelength range and the widest field of view of any material currently on the market. Constructed of a thin layer of aluminum MicroWires™ on a glass substrate, the polarizer operates from the visible through the infrared, with what Meadowlark calls outstanding performance at the telecom wavelengths. The material can be shaped as needed, used in sheet format, or sandwiched between other components at normal incidence or at 45 degrees.

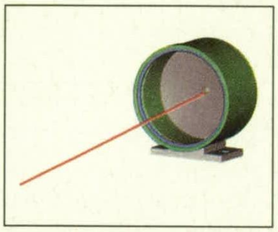
Air-Cooled Laser

Cutting Edge Optronics, St. Charles, MO, offers Repeat-a-Pulse, a 1064-nm diode-pumped air-cooled laser capable of delivering 20-ns pulsewidths and up to 12 mJ at 1-to-30-Hz operation. Cutting Edge says that the beam quality is high and the pulse-to-pulse stability means that every pulse has the same width and the same energy. The Repeat-a-Pulse is available in TEM_{00} and multimode configurations. The units are designed to be used in a constant-temperature environment. Cutting Edge recommends them for semiconductor manufacturing and repair operations, where identical pulses are essential. They are factory-sealed and maintenance-free, according to the company.



Small-Form-Factor Transmitters/Receivers

A new line of small-form-factor (SFF) dual transmitters and dual receivers for optical communications comes from Stratos Lightwave LLC, Chicago, IL. Housed in an industry-standard SFF transceiver package with two LC fiber optic interfaces, each package contains either two transmitters or two receivers. They are available in 850-nm and 1310-nm versions for any data rate up to 2.7 Gb/s. A single SFF package can be ordered with the two transmitters or receivers having the same or different data rates and operating at the same or different wavelengths.

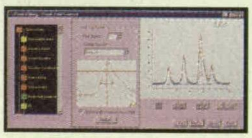


Compact Optical Transceiver

Kaiser Electro-Optics, Carlsbad, CA, introduces the Hyperscope™, a compact optical transceiver for free-space optical communications. It can be provided in 850-nm, 1310-nm, and 1550-nm wavelengths. Its aperture range is 3 to 8 in., and obscuration area is about 0.5 percent. Field of view is about 1.5 minimum. Typical line-of-sight applications for the Hyperscope include backhaul, "last-mile" networks, or situations where laying of optical fiber is not feasible.

Multi-Megapixel Camera

DALSA, Waterloo, Ont., Canada, is offering the 4M25 multi-megapixel digital camera, designed for fast, very high-resolution imaging. DALSA says the 4M25 is the first area-scan camera to combine 2048-x-2048 resolution and true 12-bit digital output at 25 frames per second. The camera's full-frame progressive-scan CCD has a 12-micron-square pixel format and a 100-percent fill factor. DALSA says it is especially good where inter-scene light variations exist. There are four camera outputs, and it comes with complete interface cable sets and Windows 95/98 control software.



Peak Fitting Module

OriginLab Corp., Northampton, MA, releases the PFM 6.1 peak fitting module, which the company says adds peak analysis functionality to Origin, the Windows-based scientific graphing and analysis software. OriginLab says that the PFM 6.1 provides an indispensable tool for spectroscopy, chromatography, and any other field requiring analysis and modeling of data with multiple peaks. The company credits the device's user-friendly interface with supporting highly interactive peak fitting. Data conditioning and adjustments to baseline, peak function, peak shape, or parameters can be done "on the fly" without having to initiate a new fitting session.

VCSEL Alignment Feature Add-On

Semiconductor Equipment Corp., Moorpark, CA, is adding two new features, a video image marker and a precising station, to the Model 410 and Model 860 Omni™ laser bonders, for enhancing precision during pickup and alignment of VCSELs with target sites on submounts such as TO headers. The optional video image marker creates and stores a fixed video overlay of crosshairs, in the form of a bit map for centering the VCSEL's emission point, as well as up to 10 different video patterns that can be superimposed on the submount on which the VCSEL is to be bonded. The precising station improves precision in VCSEL placement.

Modular Infrared Camera

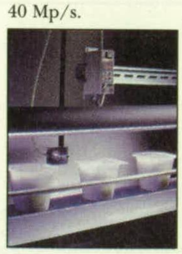
Indigo Systems, Santa Barbara, CA, says that its new Phoenix™ infrared camera family is designed to set new standards for performance and flexibility in nonvisible imaging solutions. Camera sensors are available in three spectral bands: near-IR, mid-IR, and longwave IR, with InSb, InGaAs, or QWIP snapshot focal plane arrays. Two resolutions are available: medium (320-x-256 pixels) and high (640-x-512 pixels). The system consists of a camera head and back-end electronics, which can be as much as 30 meters away from each other. All formats can produce 14-bit digital data at 40 Mp/s.

Diode-Pumped Industrial UV Laser

Coherent Laser Division, Santa Clara, CA, offers the AVIA 355-4500, a frequency-tripled Q-switched diode-pumped solid-state UV laser. The new addition to Coherent's 355-nm AVIA line produces 4.5 W of average power at 25 kHz. The AVIA 355-4500 has variable repetition rates, adjustable "on the fly" from single-shot to 100 kHz, and has pulsewidths of less than 30 ns up to 60 kHz, with what the company calls excellent pulse-to-pulse stability. The AVIA is pumped by two field-replaceable aluminum-free active-area diode modules. Its design incorporates extra-cavity doubling and tripling, allowing the third-harmonic-generating crystal to be moved without altering the head's alignment.

Color Video Display

The TFT-M25 color video display from Polaris Industries, Atlanta, GA, measures only 2 in. wide by 1.60 in. high, and 0.2 in. thick. The device has composite video (NTSC/PAL) and separate RGB video inputs. Display resolution is 480 wide by 234 high with a dot pitch of 0.105 wide by 0.161 high. The TFT-M25 weighs 25 g. The module runs off 12 VDC. Its viewing angle from left to right is 45 degrees, and up and down is 10 to 30 degrees.



Real-Time UV Power Monitor

Omron Electronics, Schaumburg, IL, introduces the F3UV, which it calls the industry's first real-time UV power monitor. The unit continuously monitors the output of UV light sources that are used for curing and sterilization purposes. The F3UV comes in two models, one with a built-in amplifier and another with a separate amplifier/optical fiber with remote head. The former comes in a die-cast structure to prevent deterioration from UV exposure, and features a large LED for easy reading. The optical fiber head can withstand temperatures up to 300 degrees C, making it suitable for UV applications where high-temperature drying is required.

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I'm researching piston loads and forces, using kinematic equations backed up by analytical software. I'm looking for a mathematical formulation on piston skirt loads. The general equations found in engineering books are only approximate, and do not delve deeply enough into the explicit nature of the "rocking effect." Any assistance would be appreciated.

Stephen Golya
glyzltn@aol.com

I read with interest the brief in the March issue of *NASA Tech Briefs* entitled "Metal-Supported Catalyst Beds for Reacting CO_2 With CH_4" by Gerald Voecks of NASA's Jet Propulsion Laboratory. This work could be the centerpiece of technology in developing partially recyclable fuels for fuel cells that could be used for clean-burning future automobiles. It may be a stretch now, but what better source for hydrogen than water? I would like to hear comments relative to, and expanding upon, the concept developed by JPL.

Michael Horvath, Jr.
michaelh@tauberoil.com

*(**Editor's Note:** Michael, there is more information available on this technology through the Technical Support Packages section of our Web site at **www.nasatech.com/tsp**. Click on the Materials category, and you'll find the associated information.)*

I can find wear rate data on Type 3 hard anodized coating, but I am trying to find wear data on Type 2 architectural anodized coating. Does anyone know where I can find such data? I'm looking for data on both sealed and unsealed Type 2 anodize. Thanks.

Steve Gonya
sgonya@stny.rr.com

I'm looking for a supplier of Peltier Cooling/Thermal Electric Units (TEUs) and some information on the temperatures they can withstand.

Robert Lehman
robert.lehman@autolivASP.com

*(**Editor's Note:** Robert, here's a response from a fellow NASA Tech Briefs reader regarding your request.)*

The standard temperature limit is 80°C, but there is also a high-temperature version that will survive up to 200°C. The coatings are very unforgiving about overheating. They are made from low-melting alloys and will simply melt down. Low temperatures are no problem as far as I know. I've cooled down to -80°C with Peltiers. You may also find additional information at www.melcor.com. Hope this helps.

Leif Kjellberg
leif.kjellberg@acreo.se

Who's Who at NASA

Anna McGowan, Morphing Project Program Manager, Langley Research Center

Anna McGowan is an aerospace engineer who serves as Program Manager for the Morphing Project at NASA's Langley Research Center in Hampton, VA. The project is focused on finding new applications for "smart" materials, as well as finding methods for applying those materials, specifically in aircraft.

***NASA Tech Briefs*: What is the mission of the Morphing Project?**

Anna McGowan: The Morphing Project division is looking 20 years or further into the future and asking what airplanes are going to look like in 20 years, and what technologies we need to be researching today to make that possible. If we want airplanes that are extremely lightweight, maybe we need structures and materials that are more like bones, or very lightweight, porous materials that are still very strong. We want wings that can handle rocks flying at them, or other damage. Can we make things that self-heal — something that you can shoot a bullet through and it heals? We are not focusing on a specific vehicle, but rather different technologies that would be applicable to a variety of different structures.

NTB: Could you explain what makes the materials you work with "smart"?

McGowan: Smart materials actually respond to a stimulus and you can control that response to your benefit. So, as an example, if you need to control vibration, you can take one of these materials that vibrates, you can control it to vibrate in the opposite direction your wing is vibrating, and you therefore control wing vibration. That's why they're called smart materials. They respond in a reproducible manner. For example, when you apply five volts, it moves six inches. Some of these materials are vibrational, which means they work better at higher frequencies. Others are more static — they move slowly but are very strong and can bend huge structures very easily. For the materials that move, you can compare those to non-smart materials like steel or wood. If you apply heat to steel or wood, they don't move. They don't do anything except maybe melt or burn.

The idea is that basically, today, to make things move, we need gears, hydraulics, pumps, cables, etc. Here, you would not need that. All you would need is the smart materials and stimuli like heat, electricity, or magnetism.

NTB: How many different types of smart materials are you working with?

McGowan: There are actually far too many to name because there are so many different variations. Nickel titanium is a very common shape-memory alloy, but you can add different elements to change different aspects of each alloy. We've mixed and created a lot of different materials, although we tend to stay with the ones we know work very well. Langley is, for all of NASA, the Center of Excellence for structures and materials, so we can create new materials here, modify existing materials, and build and test a lot of different and eccentric structures in a lot of different ways.

NTB: Have you discovered any unexpected applications for these materials that may cross over into the public sector?

McGowan: Without a doubt, we've found uses for these materials. I'll give you a classic example. The THUNDER Actuator is an actuator that was created, developed, and patented right here at Langley. It is now considered commercial and off the shelf. It is made from smart material. It's being used in all sorts of applications, including medical and pumping applications. A lot of these different materials can be tailored for medical applications, and vibration suppression in washing machines, cars, trucks, and buses. If you could shave five percent off the drag of a truck, you'd save millions of dollars in fuel.

*A full transcript of this interview appears on-line at **www.nasatech.com/whoswho.** Ms. McGowan can be reached at a.r.mcgowan@larc.nasa.gov.*

Technologies of the Month

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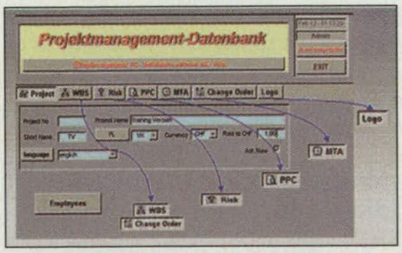
For more information on these and other new, licensable inventions, visit www.nasatech.com/techsearch

Project Management Application Provides Comprehensive Overview, Increased Efficiency

Hans Mechler, F. Hoffmann La Roche Ltd.



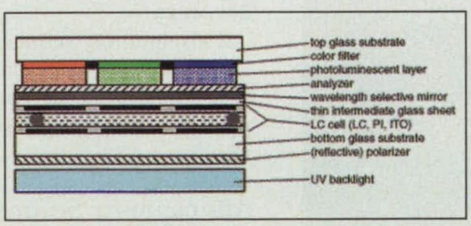
Although there are many software products that offer project management tools such as file sharing, integrated data updating and tracking, estimating, and budgeting, it is difficult to find one that integrates the whole project in one application. F. Hoffmann La Roche Ltd. and Triplan have developed a comprehensive project management software tool that integrates all information into a single database that is used to update and track every aspect of a project, including work breakdown structure, cost control, change order management, risk assessment, project process control, and milestone trend analysis.

This software tool holds enormous benefits for virtually any industry, especially those with complicated projects that require cooperation across organizational or hierarchical units.

Get the complete report on this technology at:
www.nasatech.com/techsearch/tow/roche.html

New LCD Technology Enhances Display Viewing

Tony Cupolo, Perimeter Technology, Inc.



Liquid crystal displays (LCD) are found virtually everywhere today — in personal digital assistants, cell phones, and laptops. This technology is a novel display architecture that uses photoluminescence to turn an LCD into a brighter, more energy-efficient, easier-to-see display.

The basic idea is to turn what is a transmissive or transflective display into an emissive one (ELCD). That is, to use an active or passive matrix LCD display to activate a photoluminescent display screen that offers better color purity, better contrast, a wider viewing angle, and reduced power consumption.

Low-resolution display opportunities are widespread, including industrial monitors, test and medical equipment displays, and some instrumentation displays.

Get the complete report on this technology at:
www.nasatech.com/techsearch/tow/cupolo.html

Improved Methods for Sealing and Lubricating Dynamic Groove Bearings

Marc Wolfs, Philips

Dynamic groove bearings have become popular with design engineers because of their simplicity, reliability, and virtual absence of mechanical wear. Dynamic bearings usually consist of two parts that move in close proximity relative to each other, separated by a thin film of lubricant under pressure. This technology features three new sealing methods and an active lubricant reservoir devised by Philips.

The first of the three sealing methods features an elastic O-ring held in place by a flange and rim on the two parts. The second involves manufacturing the inner bearing part with an annular raised portion and the rotating outer bearing part with an oblique surface. The third features a V-shaped annular recess in the outer bearing part that angles out from the inner bearing surface. The lubricant reservoir ensures the continuous, effective containment and distribution of lubricating fluid within the bearings.

Philips' dynamic groove sealing structures and lubricant reservoir are suited for virtually any bearing application that requires continuous motion, such as disk drives, laser scanners, CD and DVD systems, rotating magnetic recording and playback heads, and spindles.

Get the complete report on this technology at:
www.nasatech.com/techsearch/tow/philips.html

Satellite/Internet-Based Detection and Notification System

Jack Baxter, Baxter Technologies

This technology is an early detection and notification system that takes advantage of global satellite technology and the Internet. The system comprises remote environmental sensors that transmit data via satellite to a database server, which, in turn, can provide data through any number of available technologies, including computer, e-mail, telephone, pager, or the Internet.

The sensors can be modified to track environmental conditions such as hydrocarbon and toxin concentrations, atmospheric activity and water temperature, and animal migration. It also can detect and monitor airborne chemical, biological, and nuclear substances. This system is useful for monitoring or research in areas hampered by environmental conditions or remoteness.

Get the complete report on this technology at:
www.nasatech.com/techsearch/tow/baxter.html

Commercialization Opportunities

Pressure Sensor Based on Measurement of Vibration Damping

By slight modifications of the resonator and drive circuit, it may be possible to produce a device with the upper limit of 10 atm and the lower limit to $<10^{-6}$ torr.
(See page 34.)

Integrated Capacitive Wheel-Contact Sensors

Features include low power, light weight, and simplicity. These sensors are integrated into a wheel and serve to indicate contact or proximity with the ground for a small robotic vehicle.
(See page 35.)

Rare-Earth Optical Temperature Sensors

These sensors are suitable for use in harsh environments at temperatures above the maximum 1,700 °C that Pt/Rh thermocouples can withstand.
(See page 36.)

Digitally Programmable Analog Membership-Function Circuits

This invention takes advantage of both the programmability of digital circuitry and the speed and compactness of analog circuitry. The circuits are to be used in fuzzy-logic systems.
(See page 42.)

Lithium Alkoxide Electrolyte Additives for Lithium-Ion Cells

Electrolyte additives extend the lithium-ion cell operating limits from –20 °C down to –40 °C. Prototype cells that contained this electrolyte showed high charge and discharge capacities, capability to discharge at high rates, and high cycle lives at both low and room temperatures.
(See page 52.)

Filled Skutterudites as Thermoelectric Materials

These have shown promise as semiconducting materials with superior thermoelectric properties at temperatures up to at least 650 °C.
(See page 56.)

Expendable Composite-Layup Dies From Rapid-Prototype Masters

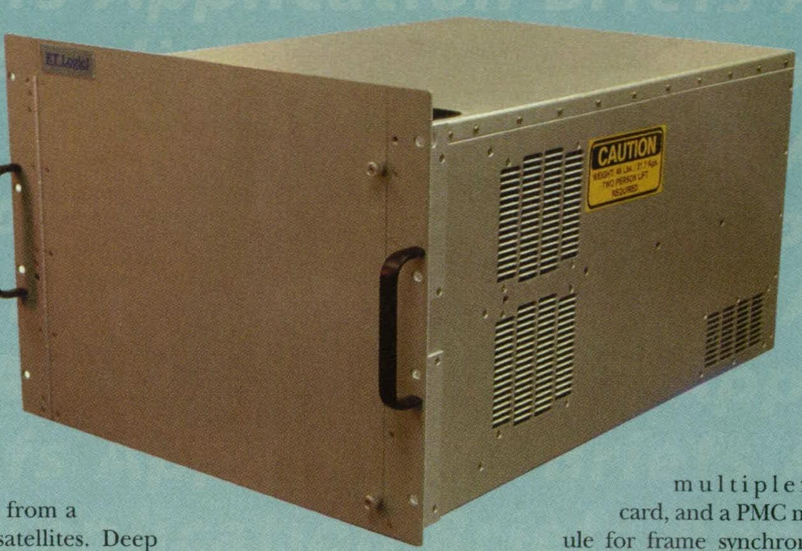
This method reduces the time and cost associated with the production of small quantities of composite-material parts that have complex shapes.
(See page 57.)

Atmospheric Source of Atomic Oxygen for Cleaning Paintings

A portable apparatus operates at atmospheric pressure to generate a beam of monatomic oxygen for restoring paintings damaged by people or the elements. The apparatus and the method can be of interest to art museums, galleries, auctioneers, and professionals working in art restoration.
(See page 61.)

Telemetry Processor Upgrades Deep Space Network

Telemetrix™ 505 telemetry processor
RT Logic
Colorado Springs, CO
719-598-2801
www.rtlogic.com



NASA's Jet Propulsion Laboratory (JPL) in Pasadena, CA, has recently upgraded the downlink telemetry processing for the Deep Space Network, using RT Logic's Telemetry Processor (TLP). The system processes a wide array of downlink signals from a variety of interplanetary and Earth-orbiting satellites. Deep Space Network is NASA's international network of antennas located at Goldstone, CA; Madrid, Spain; and Canberra, Australia.

The TLP performs digital signal processing and data routing, including Viterbi Decoding, time tagging, frame synchronization, and Reed/Solomon decoding. It routes data to and from external data decoders, and enables archival of acquired telemetry. The processor hosts JPL-developed software for further data processing required for specific missions.

Hardware for the TLP includes a 12-slot VME chassis, two PowerPC processors running the VxWorks operating system, a 9-GB hard disk drive, a 6U VME Viterbi decoder/data multiplexer card, and a PMC module for frame synchronization. RT Logic configured all of the hardware, integrated the software and hardware, created system documentation, and conducted acceptance testing.

An initial contract was awarded by JPL in October 1999 with requirements for a prototype TLP and three production units. Delivery of the prototype occurred in December 1999, and the three production TLPs were delivered in October 2000. JPL also exercised a 28-unit production option for upgrades to the ground systems at Goldstone, Madrid, and Canberra.

For More Information Circle No. 748

Power Supplies Maintain Space Station Electronics

Xantrex Model XHR power supplies
Xantrex Technology
Vancouver, BC, Canada
604-422-2759
www.xantrex.com

NASA launched on the Space Shuttle Discovery earlier this year programmable power supplies for testing and repairing electronic equipment on the International Space Station (ISS) and visiting shuttles. The ISS's main power is generated from a solar photovoltaic array at 120 volts DC, which the power supplies will convert to variable voltage levels required to test the electronic equipment, including avionics. The system is part of a portable electronics workbench that can be moved anywhere within the zero-gravity station.

At a cost of approximately $10,000 per pound to launch materials into orbit, weight is crucial. To shave more than four pounds off the weight of the 1,000-watt programmable power supplies, Xantrex switched several components from steel to lightweight aluminum. The conversion of materials also prevents condensation and rust in the high-humidity atmosphere of the ISS. A simple on/off switch was developed to allow the supply to handle the 120V DC input. The input connector was made to conform to space station standards, and bigger knobs were added for ease of use in a zero-gravity environment.

The customization process included pre-flight vibration/shake testing to ensure the power supply could withstand the G forces generated during launch. The unit also was tested at extreme hot and cold temperatures.

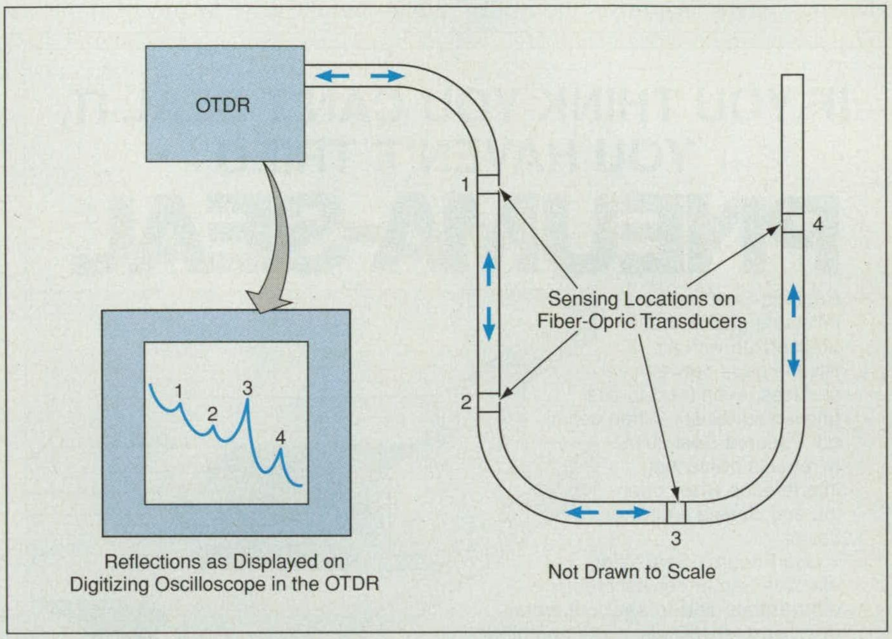
For More Information Circle No. 747

Fiber-Optic Transducers for Distributed Sensing of Volatiles: An Optical Nose

Volatiles would swell polymers on optical fibers, inducing changes in indices of refraction.

NASA's Jet Propulsion Laboratory, Pasadena, California

The term "optical nose" refers to a fiber-optic chemical sensor of a type that has been proposed to enable distributed measurement of the concentrations of volatile compounds. Optical noses should not be confused with electronic noses, which are single-point sensors based on chemical-induced variations of the electrical resistances of carbon-black/polymer composite films. Optical noses could enable rapid measurement of gas mixtures (e.g., volatile compounds in air) at multiple sensing locations along their lengths, which could be of the order of kilometers. Optical noses could function well in locations where audio- and radio-frequency electromagnetic interference renders electronic noses ineffective. Moreover, it may be easier to fabricate optical noses than to fabricate electronic noses because it would not be necessary to handle carbon black.



Volatile Compounds in the Air would give rise to local variations in the index of refraction at sensing locations along an optical fiber. The locations and magnitudes of these variations would be measured by use of optical time-domain reflectometry.

An optical nose (see figure) would include a commercially available hand-held optical time-domain reflectometer (OTDR) and a fiber-optic transducer, which would typically be prepared as follows: An optical fiber would be coated with a polymer that swells when it absorbs a volatile compound. The outer surface of the polymer would be coated with a gas-impermeable film. At designated sensing locations along the optical fiber, the impermeable film would be removed in patterns to form half-circumference, millimeter-wide notches through which gases could enter the polymer.

The absorption of one or more volatile compounds through the notch at a given sensing location would give rise to asymmetric swelling of the polymer; the asymmetric swelling would engender shear stress which, in turn, would cause local variation in the index of refraction of the fiber. (Optionally, the notches could extend the full circumference, in which case the swelling and the resulting shear-stress pattern would be symmetric. However, the asymmetric configuration is preferred because the shear stress and the associated change in the index of refraction would be greater.)

The OTDR would launch picosecond laser pulses into the optical fiber at one end. The index-of-refraction variations associated with the presence of volatile compounds at the notches would cause part of the incident laser light to be reflected. The OTDR would make time-resolved measurements of the intensity of the reflected laser light. For a given reflected pulse, the location of the corresponding sensing notch could be inferred from the measured round-trip pulse travel time.

It should be possible to construct arrays of optical noses for discrimination among different volatile compounds. Each fiber-optic transducer in such an array would be coated with a different polymer, which would be chosen so that the index-of-refraction response of this transducer to different volatile compounds of interest would differ from the corresponding responses of the other transducers. For automated or semiautomated operation, the readouts of all the transducers in the array could be digitized, then processed by principal-component-analysis and pattern-recognition algorithms to discriminate the volatile compounds of interest.

This work was done by Adrian Ponce and Dmitri Kossakovski of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

Technology Reporting Office
JPL
Mail Stop 249-103
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-2240

Refer to NPO-21105, volume and number of this NASA Tech Briefs *issue, and the page number.*

Pressure Sensor Based on Measurement of Vibration Damping

Attributes include high resolution, wide dynamic range, compactness, and low power.

NASA's Jet Propulsion Laboratory, Pasadena, California

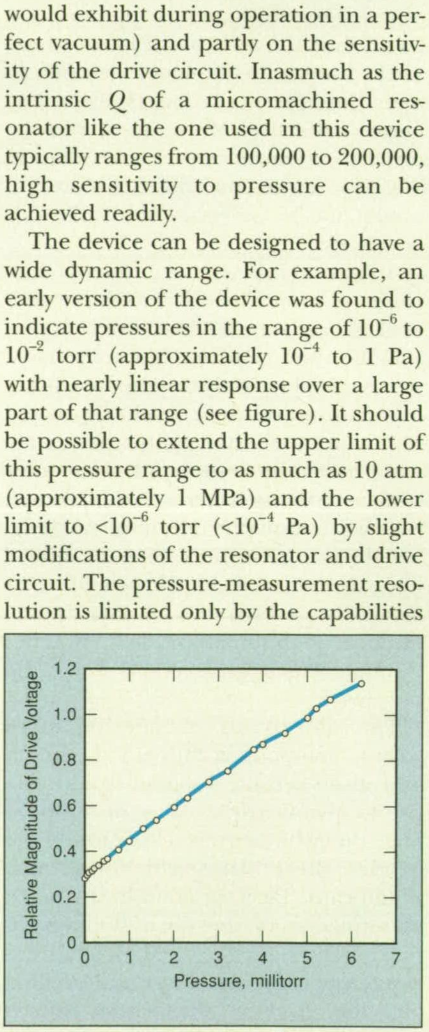
A compact, low-power device measures pressure via the pressure-induced damping of oscillation of a small mechanical resonator. To achieve compactness and low mass — and thus low-power consumption — the resonator is micromachined out of silicon. In addition to the resonator, the device includes an electronic circuit that drives the oscillation and effectively measures the resonance quality factor (Q), which is inversely proportional to the rate of damping.

The drive circuit generates a drive voltage that alternates at the frequency of the mechanical resonance. The circuit tracks the mechanical resonance to maintain the drive frequency at the resonance frequency, even when the resonance frequency drifts gradually with time or with changes in temperature. The drive voltage is applied to electrostatic-deflection electrodes to excite and maintain the oscillation. The circuit includes a feedback loop that measures the amplitude of the oscillation and adjusts the drive voltage to maintain the oscillation at a preset amplitude.

At a given time, the magnitude of the drive voltage needed to maintain the preset amplitude of oscillation depends on the rate of damping and thus on the pressure at that time. Accordingly, the magnitude of the drive voltage developed by the feedback loop is sampled and taken as an indication of pressure.

The overall sensitivity of the device depends partly on the intrinsic Q of the resonator (the Q that the resonator would exhibit during operation in a perfect vacuum) and partly on the sensitivity of the drive circuit. Inasmuch as the intrinsic Q of a micromachined resonator like the one used in this device typically ranges from 100,000 to 200,000, high sensitivity to pressure can be achieved readily.

The device can be designed to have a wide dynamic range. For example, an early version of the device was found to indicate pressures in the range of 10^{-6} to 10^{-2} torr (approximately 10^{-4} to 1 Pa) with nearly linear response over a large part of that range (see figure). It should be possible to extend the upper limit of this pressure range to as much as 10 atm (approximately 1 MPa) and the lower limit to $<10^{-6}$ torr ($<10^{-4}$ Pa) by slight modifications of the resonator and drive circuit. The pressure-measurement resolution is limited only by the capabilities



Nearly Linear Response was observed at pressures less than about 6 millitorr (0.8 Pa).

of the drive circuit; it should be possible to design the circuit to achieve a resolution of $< 10^{-6}$ torr ($<10^{-4}$ Pa) over the extended pressure range.

This work was done by Roman C. Gutierrez, Tony K. Tang, Jaroslava Wilcox, William J. Kaiser, Christopher B. Stell, Vatche Vorperian, and Kirill V. Shcheglov of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Management Office–JPL; (818) 354-4770. Refer to NPO-20052.

Integrated Capacitive Wheel-Contact Sensors

Features include low power, light weight, and simplicity.

NASA's Jet Propulsion Laboratory, Pasadena, California

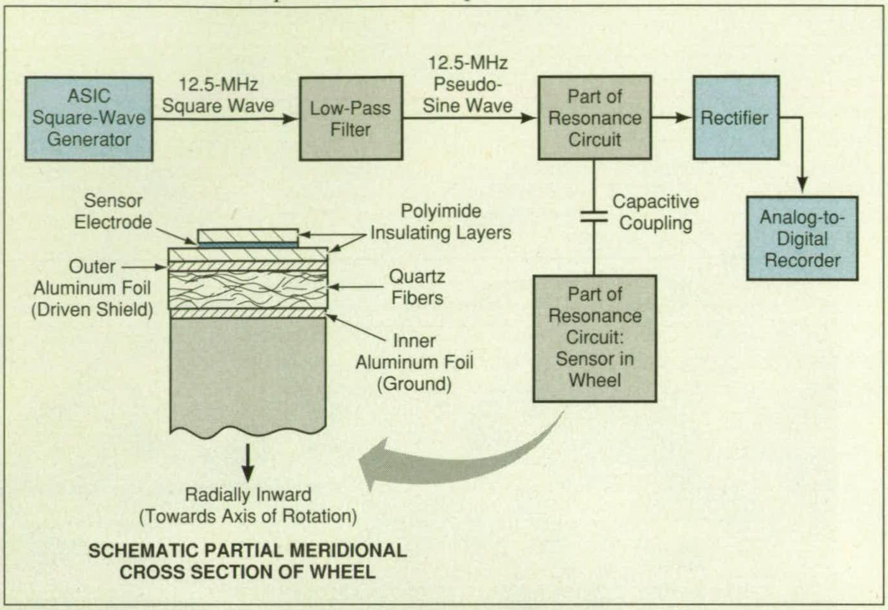
A low-power capacitive proximity sensor has been developed as a prototype of wheel-contact sensors for a small robotic vehicle. The sensor is integrated into a wheel and consists of only a few components that add very little mass to the wheel. The output of the sensor serves as an indication of contact with (or proximity of) the ground; this output can be used as feedback for a vehicle control system. An important aspect of the circuit design is the use of capacitive (instead of slip-ring) coupling between the sensor circuit and associated external circuitry; in comparison with a slip ring, a capacitive coupler is more reliable, less electrically noisy, lighter in weight, and less mechanically complex.

The figure schematically depicts the sensor and the associated external circuitry. An application-specific integrated circuit (ASIC) generates a 1/2-duty-cycle square wave with a repetition frequency of 12.5 MHz. The square-wave signal is low-pass filtered to obtain a 12.5-MHz pseudo-sine wave for excitation of the sensor.

The sensor includes an inner aluminum foil ring covered by a layer of quartz glass fibers, covered in turn by an outer aluminum foil ring, over which are wrapped a ring of polyimide sheet and

then a narrower ring of metallized polyimide sheet. The innermost aluminum foil ring acts as electrical ground. The outer aluminum foil ring acts as a driven shield, which is excited in phase with the sensor electrode described next. The metal layer on the metallized polyimide sheet serves as the capacitive sensor electrode, which is part of an inductor/capacitor/resistor circuit that resonates at a frequency of 11 MHz in the absence of nearby objects.

Proximity of the ground or an obstacle manifests itself through the effect of the ground or obstacle material on the capacitance of the sensor electrode. Typically, contact with the ground or an obstacle causes the capacitance to change by an amount between 0.3 and 1.3 pF. The change in capacitance causes a change in the resonance frequency and thus a change in signal amplitude along the slope of a voltage-vs.-frequency resonance curve at a suitable measurement point in the sensor circuit. The voltage is sampled at the measurement point and converted to a dc output voltage, which is then digitized for further processing by the vehicle control system.



A **Capacitive Proximity Sensor** is built into a wheel and is capacitively coupled to associated external circuitry.

This work was done by R. Scott Cozy, Brian Wilcox, and Mike Newell of Caltech and John Vranish of Goddard Space Flight Center for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*
NPO-20787

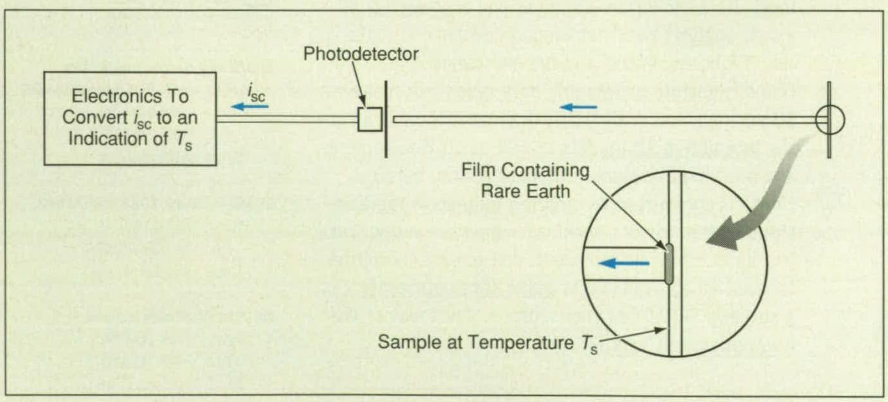
Rare-Earth Optical Temperature Sensors

These sensors exploit the narrow-band emission peculiar to rare earths.

John H. Glenn Research Center, Cleveland, Ohio

A recently developed type of fiber-optic temperature sensor utilizes narrow-band near-infrared radiation emitted by rare-earth ions. These sensors are suitable for use in harsh environments at temperatures above the maximum (1,700 °C) that Pt/Rh thermocouples can withstand. The maximum operating temperature for these optical temperature sensors can equal or exceed 2,000 °C, the exact values depending on the choice of fiber-optic and rare-earth-containing radiative materials. The minimum temperature measurable by use of a sensor of this type, related to the minimum detectable radiation, has been found to be ≈700 K (≈427 °C).

Most atoms and molecules at solid-state densities emit electromagnetic radiation in continuous spectra much like those of black bodies. However, even at solid-state densities, the rare earths emit radiation in narrow bands much like those of isolated atoms — a consequence of the electron wave functions peculiar to the rare earths. The development of the present rare-earth optical temperature sensors is a result of prior research on rare-earth-containing selective emitters for thermophotovoltaic energy conversion. In that research, it was found that rare-earth-doped yttrium aluminum garnet ($Re_xY_{3-x}Al_5O_{12}$, where Re = signifies Yb, Er, Tm, or Ho) is an excellent selective emitter. It is chemically stable at high temperatures (>1,500 °C) and is characterized by emittances of ≈0.7 in the near-infrared wavelength range of interest for measuring temperatures.



Narrow-Band Infrared Light emitted by rare-earth ions in a film in contact with a hot sample is measured to obtain an indication of the temperature of the sample.

A sensor of this type (see figure) is an optical fiber, coated at its input (hot) end with a film that contains a rare earth. The rare-earth-containing tip of the fiber is placed in contact with the object, the temperature of which is to be determined. Infrared radiation emitted at the input end of the optical fiber travels to the output end of the fiber, then through a band-pass filter with a narrow pass band that lies within the emission

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For More Information Circle No. 561

wavelength band of the rare earth. The filtered radiation impinges on a photodetector, the output of which is processed to obtain an indication of temperature.

Assuming that the photodetector is a photovoltaic device that is operated in a short-circuit configuration, it has been shown theoretically that the absolute temperature, T_s, of the hot sensor tip should be given by

$$T_s = [T_c^{-1} + (\lambda_f k/hc_0)\ln(i_c/i_{sc})]^{-1}$$

where T_c is a known calibration temperature, λ_f is the middle wavelength of the filter pass band, k is Boltzmann's constant, h is Planck's constant, c_0 is the speed of light in a vacuum, i_c is the short-circuit detector current measured when the sensor tip is at the calibration temperature, and i_{sc} is the short-circuit detector current measured when the sensor tip is at the temperature, T_s, that one seeks to determine.

A prototype sensor was constructed with a sapphire optical fiber tipped by an $Er_3Al_5O_{12}$ emitter, a chopper, a filter of λ_f = 1,012 nm, a silicon photodetector, and a lock-in amplifier for measuring the short-circuit detector current. The prototype sensor was calibrated at a temperature of 1,879 K. Then temperatures calculated from i_{sc} readings by use of the equation given above were compared with simultaneous thermocouple measurements. The results of these measurements showed the worst-case fractional temperature error to be only 0.03, thereby confirming the validity of the equation and the underlying temperature-measurement principle.

This work was done by Donald L. Chubb and David S. Wolford of **Glenn Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

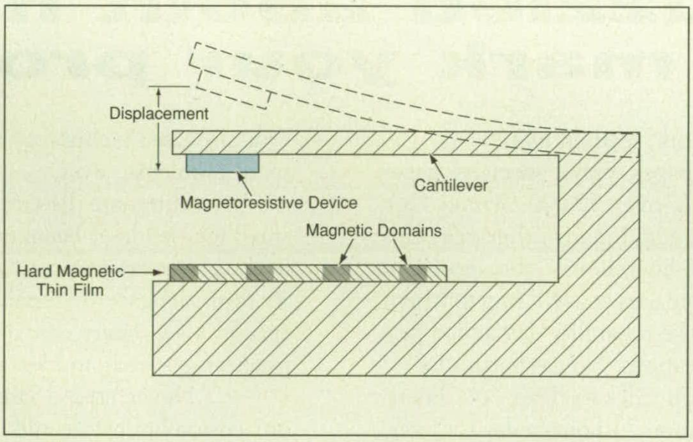
Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17138.

Microelectromechanical Sensors Based on Magnetoresistance

These would offer advantages over similar sensors based on quantum-mechanical tunneling of electrons.

NASA's Jet Propulsion Laboratory, Pasadena, California

Microelectromechanical sensors based on magnetoresistance have been proposed. Like other microelectromechanical sensors, these would be used to measure physical quantities that can be made to manifest themselves in small mechanical displacements. Potential applications for microelectromechanical sensors include accelerometers, magnetometers, bolometers, pressure sensors, seismometers, Golay cells, and microphones. Potential markets include the aerospace, biomedical, semiconductor, automotive, and defense industries.



The **Magnetoresistive Device** would be used to measure the local strength of the magnetic field of the film. Because the magnetic-field strength would depend on the distance from the film, the measurement would indicate the displacement of the cantilever from the equilibrium position.

Similar microelectromechanical sensors based on quantum-mechanical tunneling of electrons at movable tips of diaphragms, cantilevers, and other flexible members have been developed, and have been reported in a number of previous articles in *NASA Tech Briefs*. The fabrication and electrical characterization of the tunneling-based sensors have proven to be difficult. Operation has proven to be difficult in that tunneling tips must be kept spaced about 1 nm apart; tips often crash together, with consequent damage, leading to rejection of parts.

The proposed sensors are expected to be less problematic, because they would be manufactured and operated by use of techniques that have become well established in the data-storage (computer-disk) industry. In a typical sensor of proposed type, a magnetoresistive device mounted on a diaphragm or near the free end of a cantilever in a magnetic-field gradient (see figure) would be used to measure the field strength and thus, indirectly, the distance from the source of the magnetic field. This distance would, in turn, be indicative of the displacement of the diaphragm or cantilever from an equilibrium distance. The magnetic field would be provided by a hard magnetic thin film attached to the relatively stationary portion of the device structure, facing the magnetoresistive device. The strength and gradient of the magnetic field would depend partly on the thickness of the film and partly on the distances between magnetic domains in the film.

Unlike in a tunneling-based sensor, it would not be necessary to maintain a distance of about 1 nm or less between tunneling tips; instead, the film thickness and thus the magnetic-field strength could be increased to enable the use of a greater equilibrium distance between the magnetoresistive device and the film, making the proposed sensor less vulnerable to damage. Also, inasmuch as techniques for measuring magnetic fields are well established in the data-recording industry, magnetic-field changes corresponding to sub-nanometer displacements could be measured accurately.

This work was done by John D. Olivas and Bruce Lairson of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Management Office–JPL; (818) 354-4770. Refer to NPO-20146.

Capacitive Sensor for Measuring Level of Liquid Nitrogen

The liquid is used as a dielectric layer in a parallel-plate capacitor.

Lyndon B. Johnson Space Center, Houston, Texas

The feasibility of a capacitive sensor for measuring the level of liquid nitrogen in a container has been demonstrated. The basic sensor design could also readily be adapted to measurement of the levels of cryogenic liquids other than nitrogen.

The general concept of capacitive sensors is not new. The novel aspect of this particular capacitive sensor lies in the use of the liquid nitrogen as part of the dielectric of a capacitor. Two vertically parallel, electrically conductive plates constitute the electrodes of the capacitor and are partly immersed in the liquid from the top, so that the top surface of the liquid lies somewhere along the plates. As the level of the liquid varies, the amount of dielectric material between the plates, and thus the capacitance, also varies. It is possible to compute the level of the liquid from (1) a measurement of the capacitance or a quantity related to capacitance in a known way and (2) the known relationship between the liquid level and the capacitance.

Several other types of sensors for measuring the levels of cryogenic liquids are available. The transducers in those sensors include, variously, cryodiodes, carbon resistors, hot-wire sensors, and simple floats. Each type is disadvantageous in one or more ways:

- Cryodiodes are expensive (costing about $500 apiece), and the electrical currents through them must be conditioned in order to enable detection of liquid/vapor interfaces for proper measurement of liquid levels.
- Because carbon resistors are insensitive to liquid/vapor interfaces, they give only rough indications of the levels of cryogenic liquids.
- Hot-wire sensors can give inaccurate readings when liquids boil next to the wires.
- Simple floats provide good visual indications of liquid levels, but their outputs cannot be fed directly to computer data-acquisition systems.

The first step in the development of the present capacitive sensor was to establish the relative permittivity of liquid nitrogen ($\approx$1.454), gaseous nitrogen (1.0005480), and air (1.0005364) at the boiling temperature of liquid nitrogen at standard atmospheric pressure. The electrodes of a prototype of this sensor were made from two copper-clad circuit boards with a thickness of 0.010 in. (0.254 mm), a length of 10 in. (25.4 cm), and a width of 1 in. (2.54 cm). The boards were secured with five nylon screws, nuts, and washers spaced 0.070 in. (1.78 mm) apart. A wire was soldered to the top of each plate, and the wires were attached in parallel to another capacitor that constituted part of the time base of a free-running oscillator. The plate structure was placed inside a Dewar flask, into which liquid nitrogen was poured. As the liquid level increased, the capacitance of the plate structure likewise increased. In subsequent demonstrations, this prototype sensor performed consistently, and thus its capability was proved conclusively.

This work was done by Tim E. Roth of AlliedSignal, Inc., for **Johnson Space Center**. *For further information, contact the Johnson Space Center Commercial Technology Office at (281) 483-0474.*

MSC-22792

Black Jack GPS Receiver

NASA's Jet Propulsion Laboratory, Pasadena, California

The Black Jack (BJ) receiver is the revolutionary flight Global Positioning System (GPS) receiver developed by NASA to fill future needs for orbit-based GPS science. These range from a receiver to determine precise (1-cm radial accuracy goal for JASON-1) orbits, to missions using the GPS signals for remote sensing of the Earth's atmosphere. The BJ receiver follows the TurboRogue space receiver, which was successfully used in collaboration with engineers and scientists at JPL on five satellite missions. While the TurboRogue was initially designed as a high-accuracy ground receiver, the BJ was designed from the start as an instrument for use from orbit. The BJ contains many innovations to better suit it to this application. In order to simplify the analog electronics, it directly samples the amplified and filtered RF (radio-frequency) signal. This sampling produces two sample streams in quadrature for improved SNR (signal-to-noise ratio). The BJ semicustom Application Specific Integrated Circuit (ASIC) uses a full matrix switch so that inputs from multiple antennas can be directed to any of 48 tracking channels. Other ASIC capabilities are telemetry reception, tone tracking, and precise time tagging of external events. Although the receiver is designed as a science instrument rather than for mission-critical operation, it does contain innovative features such as the capability to operate in a bit-grab mode. In the event the highly-redundant digital processing fails, the main processor stops, or the spacecraft can no longer power the GPS receiver, the BJ can turn on for less than a second every hour, and still transmit data to the ground allowing sub-100-m orbit determination. The BJ receiver is designed with excess processor capacity to allow it to perform non-GPS functions; for example, on the GRACE mission, the BJ controls an intersatellite K-band link and also processes the output of a star camera to determine spacecraft attitude.

This work was done by Thomas Meehan, Jeffrey Srinivasan, Jeffrey Tien, Garth Franklin, Donovan Spitzmesser, Timothy Munson, and Charles Dunn of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Black Jack GPS Receiver," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

Technology Reporting Office
JPL
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Refer to NPO-20891, volume and number of this NASA Tech Briefs *issue, and the page number.*

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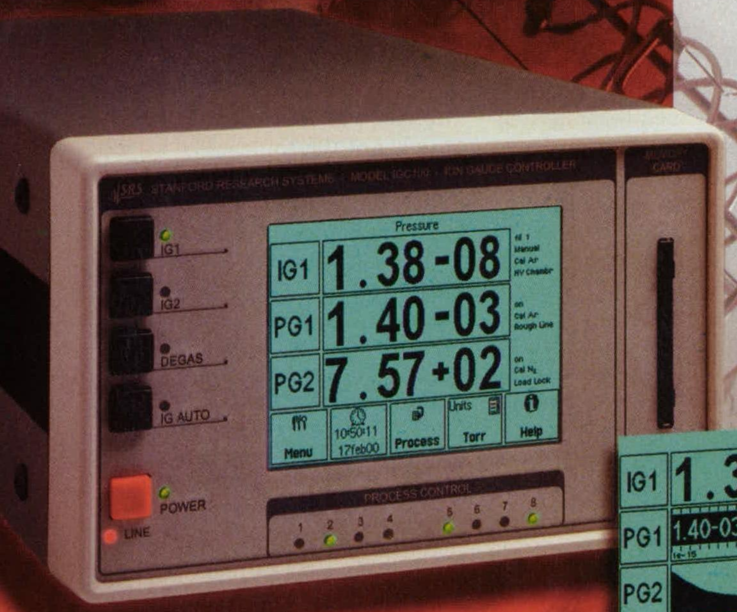

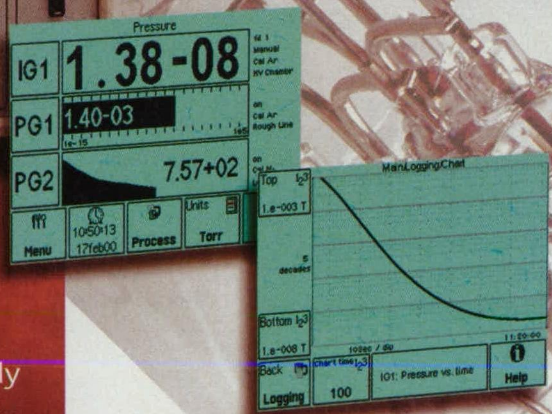

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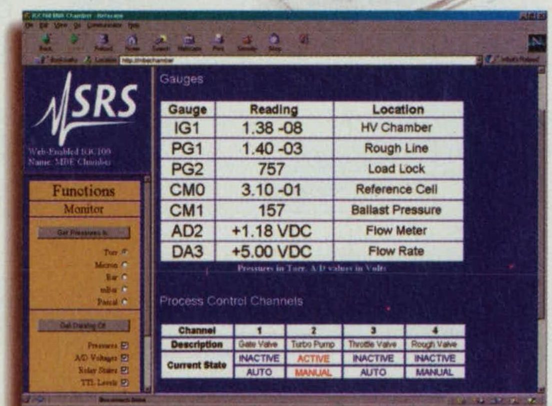

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Digitally Programmable Analog Membership-Function Circuits

These circuits exploit the best features of analog and digital implementations.

NASA's Jet Propulsion Laboratory, Pasadena, California

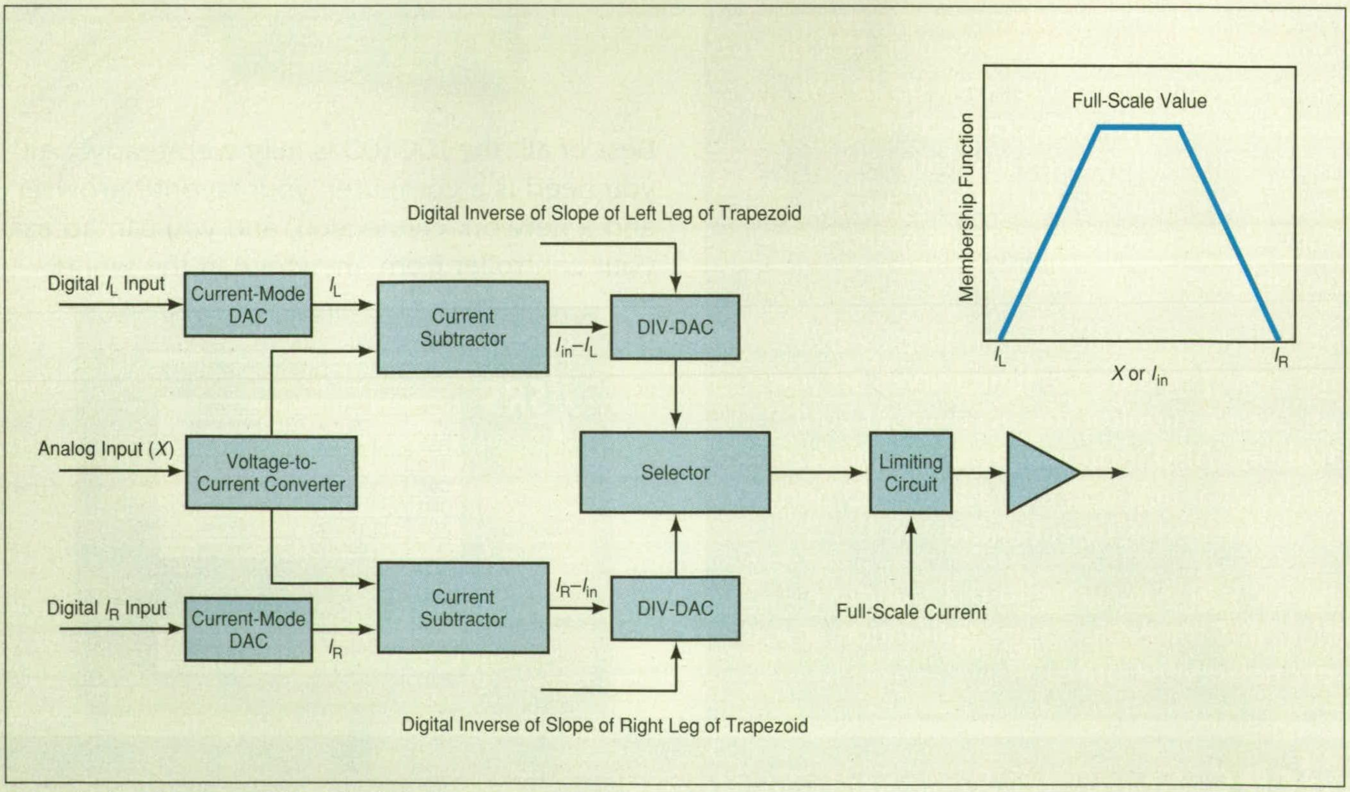
Digitally programmable analog membership-function circuits have been invented for use in fuzzy-logic systems. Heretofore, fuzzy membership functions have been implemented, variously, by use of purely analog or purely digital circuits. Purely digital circuits afford flexibility at the cost of less speed and greater circuit area. Purely analog circuits offer greater speed and occupy less area but tend to be limited in flexibility and programmability. The present invention takes advantage of both the programmability of digital circuitry and the speed and compactness of analog circuitry. The analog aspect of the invention creates the potential for high-speed parallel processing with relatively low power consumption.

In designing a circuit according to the invention, one uses current-mode circuitry to implement fuzzification in a fully parallel architecture while using a digital interface for programmability of attributes of membership functions. In a typical case, a membership-function circuit accepts an analog input potential and implements a trapezoidal membership function (see figure). First, the input potential signal (X) is converted to a current-mode signal (I_{in}) for further processing. Two current-mode digital-to-analog converters (DACs) provide currents I_L and I_R that represent zero-crossing locations of the left and right legs, respectively, of the trapezoidal membership function.

Current subtractors generate $I_{in} - I_L$ and $I_R - I_{in}$, and feed these difference currents as analog inputs to dividing digital-to-analog converters (DIV-DACs). [Alternatively, one could use multiplying digital-to-analog converters (M-DACs); the advantage of DIV-DACs is that they provide more evenly spaced increments, which makes the range of programmable slopes more useful.] The digital input to each DIV-DAC is a number inversely proportional to the slope of the corresponding leg of the trapezoidal membership function. In each DIV-DAC, the analog difference-current input is divided by the digital inverse-slope input to obtain the ordinate on the affected leg of the trapezoid. A comparator circuit selects the output of either the left- or the right-leg DIV-DAC, and a limiting circuit clips the output at a level corresponding to the top of the trapezoid. The output current of the limiting circuit is converted to an output voltage.

This work was done by Tyson Thomas and David Weldon of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

NPO-20810



A Combination of Analog and Digital Circuits implements a trapezoidal membership function of an analog input signal. The digital inputs establish the parameters of the trapezoid.

Regenerative Pseudonoise Ranging

The effective return ranging power could be increased greatly.

NASA's Jet Propulsion Laboratory, Pasadena, California

In a proposed improved technique for pseudonoise turnaround ranging of a radio transponder, the pseudonoise modulating signal would be regenerated in the transponder. The net result of the regeneration would be an increase in the effective return ranging power. This increase would provide some margin for decreasing ranging time, decreasing the power of the return ranging signal transmitted by the transponder, or increasing the power of another (e.g., telemetric) signal transmitted from the vehicle that carries the transponder. The technique was conceived for use in measuring the distance between a master station on Earth and a spacecraft that carries a transponder; with modifications, it may also prove useful in other applications that involve ranging and/or communications in both outer-space and terrestrial settings.

In turnaround ranging, one determines the distance between the master station and the transponder by measuring the round-trip travel time for a known ranging signal modulated onto a carrier signal (denoted the uplink carrier signal) transmitted by the master station. The receiver in the transponder locks onto the uplink carrier signal, demodulates the ranging signal, and remodulates the ranging signal onto another carrier signal (denoted the downlink carrier signal), which is coherently related to the uplink carrier. A receiver at the master station locks to the downlink carrier signal and demodulates the ranging signal. Finally, the received ranging signal is correlated with the transmitted ranging signal, and the offset between the two signals that yields the maximum correlation amplitude constitutes the estimate of the round-trip signal travel time.

In this case, the ranging signal would be a pseudonoise binary sequence that would be phase-modulated onto the uplink carrier. Pseudonoise binary sequences have been used before in turnaround ranging of spacecraft because they offer a desirable combination of high ranging resolution, low ranging ambiguity, and no need for receivers to "know" when pseudonoise sequences started.

The need for regeneration of the pseudonoise sequence (or, for that matter, any other ranging signal) in a transponder arises as follows: In the transponder, in the absence of regeneration, uplink noise is received along with the ranging signal, so that unavoidably, the uplink noise is modulated onto the downlink carrier along with the ranging signal. In a typical deep-space application, the retransmitted uplink noise power can exceed the retransmitted ranging power by as much as 30 to 40 dB. Thus, a considerable amount of power that could otherwise be used for telemetry or other purposes is wasted retransmitting the uplink noise, and the retransmitted noise degrades the ranging signal received at the Earth or other master station. If the pseudonoise sequence could be regenerated in the transponder with proper timing instead

of being simply turned around along with the uplink noise, then it could be retransmitted without the uplink noise, thereby increasing the ranging-signal-to-noise ratio.

The major task for the transponder at any given time is to determine the current position in the pseudonoise sequence in order to regenerate and retransmit the sequence with proper timing. Part of this task is to determine the current phase of the ranging signal. Assuming that the ranging signal is frequency-coherent with the uplink carrier signal, following standard practice in turnaround ranging, the proposed technique would involve locking to the received uplink carrier signal to obtain a timing signal for a numerically controlled oscillator in a pseudonoise-sequence-tracking loop (also called a "chip-tracking" loop).

Because the ranging signal would look like a square-wave signal except for an occasional flip in polarity, the phase of the signal would be tracked by use of a first-order square-wave phase-locked loop. The nature of the pseudonoise sequence would be such that the tracking phase error would average out to zero in the long term, and the effect of the tracking phase error could be diminished through low-pass filtering. Because the phase-error output of a phase-locked loop is proportional to the signal amplitude, which can vary widely, an automatic gain control (AGC) would be necessary for normalizing the amplitude before input to the loop filter. The reference amplitude signal for the AGC would be the amplitude of the signal in the in-phase channel of the carrier-tracking loop.

The chip-tracking loop would contain correlators instead of a traditional lock detector. The correlators would integrate over a desired number of pseudonoise-repetition periods (chips), and the current position relative to the pseudonoise sequence would be determined from the correlator outputs. The timing of the transmitting pseudonoise-sequence generator would be set accordingly, and the numerically controlled oscillator in the chip-tracking loop would be used to clock the binary modulation sequence to the downlink transmitter. After each integration period, the current positions in the transmitted and received pseudonoise sequences would compared; agreement of these positions would signify lock.

This work was done by Jeff Berner, James M. Layland, Peter Kinman, and John R. Smith of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*
NPO-20846

Biomorphic Analog Pulse-Coupled Neural Circuits

These circuits are potentially useful for invariant pattern recognition.

NASA's Jet Propulsion Laboratory, Pasadena, California

Analog electronic circuits that operate with pulsed input and output signals are undergoing development. The pulsing behavior of these circuits is modeled after a similar behavior, called "spiking," that occurs in biological neural networks. In these circuits, the pulse times and/or the pulse-repetition rates can convey information. These circuits are intended especially for use in high-speed artificial neural networks, which, like the brains of animals that have vision, would process image data to effect invariant pattern recognition. (As used here, "invariant"

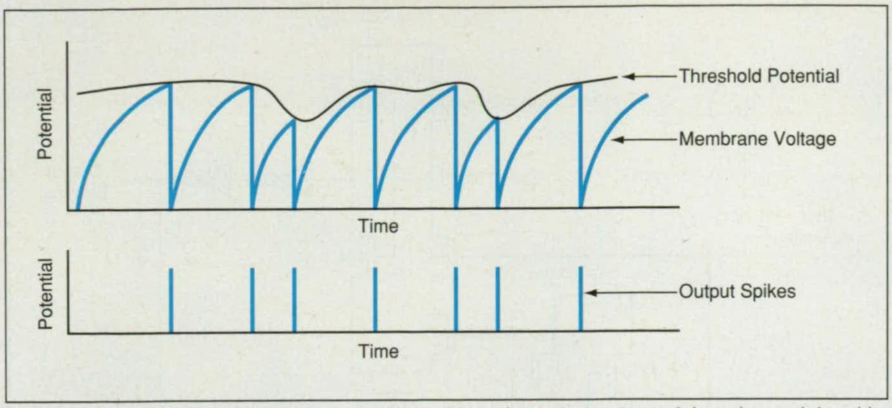


Figure 1. The **Interval Between Spikes and the Buildup of Membrane Potential** can be modulated by modulating the threshold potential.

signifies that the ability to recognize patterns would not be adversely affected by such effects as translation, rotation, distortion, changes in scale, or changes in brightness.)

Figure 1 depicts an example of input/output behavior according to one mathematical model of a biomorphic spiking neuron. Starting from the beginning of a pulse cycle, a membrane potential rises at rate that decays exponentially until the potential passes a time-varying threshold, at which point the neuron sends a spike along its axon. At the instant of the spike, the membrane potential returns to a resting level from which the cycle starts anew. If the threshold, the resting potential, or the rate of rise of the membrane potential is modulated, then the pulse-repetition rate (also called the "spiking frequency" or the "firing rate") of the neuron is changed.

By locally connecting neurons like this one into an array in which the axons of neighbors would transmit their spike trains via synapto-dendritic connections that would modulate the thresholds, one could construct a complex processing network. In a computational simulation, such a network has been shown to be capable of invariant mapping of binary patterns.

The invariance of the mapping is a result of encoding images in time rather than space. In particular, if the same image is fed as input to a different set of pixels but the same spatial relationships are maintained among parts of the image, the temporal representation of the image remains the same and the mapping is invariant to translation. Invariance with respect to brightness is achieved partly by recognizing that greater brightness is represented simply by a uniform increase in the average firing rates of all affected neurons.

The upper part of Figure 2 depicts a developmental spiking-neuron circuit. The clock voltage source (V_{clk}) pumps charge through a subthreshold biased transistor (M1) onto the gate capacitance of transistor M2, the gate potential of which represents the membrane potential. The current source constituted by the clock and M1 is intentionally made fairly poor (i.e., is made to have low resistance) in order to obtain a nonlinear buildup of membrane po-

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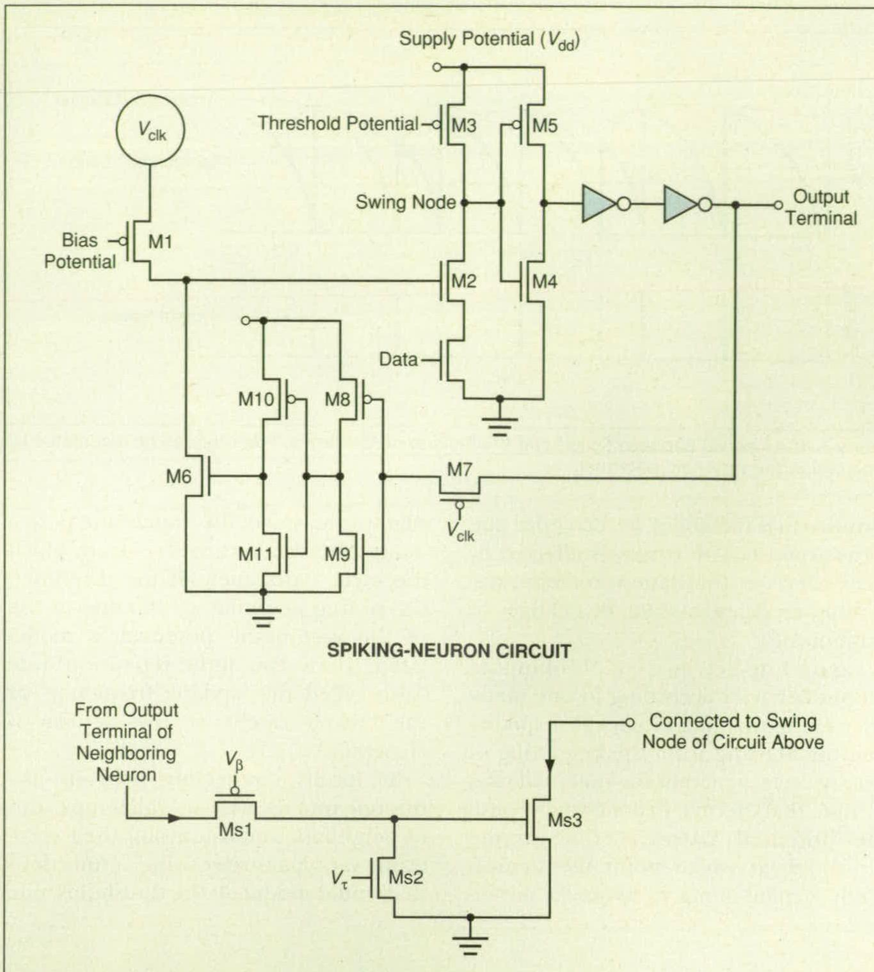

Figure 2. These **Analog Neural Circuits** are designed to exhibit spiking behavior that approximates that of Figure 1.

tential. When the membrane potential becomes high enough to pull M3 out of its linear current-vs.-voltage region, the voltage at the swing node rapidly decreases as M2 pulls the node toward ground. The low voltage on the swing node then triggers the inverter formed with M4 and M5 to go high, and the inverter potential is digitally buffered to the output terminal. The clocked switching transistor M7 latches the voltage output on the noncharging portion of the cycle of the current pump at M1. M8 and M9 are sized to constitute an inverter that triggers at a relatively high dc potential to insure an adequate spike amplitude before the discharge transistor M6 is activated. When M6 is switched on, all charge at the membrane is drained to ground (zero potential) or, alternatively, to a source of nonzero resting potential connected to the source terminal of M6. When the membrane potential falls, M2 shuts down and the swing node is pulled high again as M3 returns to its linear region. This change in the swing node returns the output to low, ending the spike and switching off the discharge transistor at M6.

The lower part of Figure 2 shows a synapto-dendritic input circuit connected to the swing node of a spiking neuron. In a locally connected network, there could be eight input circuits like this one for coupling the outputs from eight nearest-neighbor neurons as inputs to the affected neuron. Transistor Ms1 sets the gain of the coupling, while transistor Ms2 controls the timing. Essentially, the spike from a neighboring neuron injects charge onto the gate of Ms3 through Ms1. This charge then slowly leaks away via Ms2 to produce a decaying exponential current response through Ms3. This current modulates the threshold of the spiking neuron by pulling M3 closer to saturation, thereby enabling a decreased membrane potential to trigger a spike.

This work was done by Tyson Thomas of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*
NPO-20818

Weighing Scales Based on Low-Power Strain-Gauge Circuits

Small solar batteries would provide the necessary power.

NASA's Jet Propulsion Laboratory, Pasadena, California

Weighing scales (e.g., kitchen and bathroom scales) of a proposed type would incorporate sensory devices like the one described in "Low-Power, Microprocessor-Controlled Strain-Gauge Circuit" (NPO-19750), *NASA Tech Briefs,* Vol. 21, No. 1 (January 1997), page 45. Unlike other weighing scales based on strain gauges, these would not require electrochemical batteries or external power supplies; instead, the proposed scales could be powered adequately by solar batteries like those included on some pocket electronic calculators.

In a weighing scale of the proposed type, power consumption much lower than that of conventional strain-gauge circuits would be achieved by a unique combination of novel and conventional features. As explained in more detail in the earlier article, the intermittency of the operation of the microprocessor-controlled strain-gauge circuit would contribute a major portion of the reduction in time-averaged power. A further reduction would be effected by use of a strain gauge of unusually high electrical resistance — about 3 kΩ instead of the customary value of about 120 Ω. Ordinarily, the use of the lower resistance would be dictated by the need to minimize noise pickup on strain-gauge-output wires, where the noise voltage can be comparable to the strain-gauge output voltage. In this case, however, the strain-gauge circuit would be very small and one could mount the rest of the strain-gauge circuit very close to the strain gauge; this would make it possible to shorten the electrical connections and thereby reduce noise pickup, enabling the use of the higher gauge resistance without incurring excessive noise.

A preliminary estimate shows that with a 3-kΩ strain gauge and associated circuitry operating at a supply potential of 3 V at a sampling rate of twice per second with sampling periods 100 µs long, the overall time-averaged power consumption would be about 12 µW. A typical calculator-type solar battery supplies a current of about 10 µA at a potential of 3 V (power of about 30 µW) under full illumination. Thus, one such battery would provide at least 50 percent power margin to allow for reduced illumination.

As explained in the earlier article, the strain-gauge circuit would automatically correct for variations in the supply voltage. The microprocessor in the strain-gauge circuit could also be programmed to correct for nonlinearity in the strain-gauge response, and to provide a digitally controlled analog offset to correct for tare weight.

This work was done by Shannon P. Jackson and Harold Kirkham of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*
NPO-19777

Generating Maps of the Ionosphere From GPS Measurements

The Global Ionospheric Monitoring and Forecasting System (GIMSYS) computer program generates global maps of the total electron content (TEC) (electron density integrated over all altitude) of the ionosphere, maps of ionospheric irregularities, and related data byproducts. The maps are generated primarily from signal-propagation measurements taken by more than 100 continuously operating two-frequency Global Positioning System (GPS) receivers in a world-wide network. GIMSYS interpolates the measurements temporally and spatially generating a global TEC map every 15 minutes. When updating the map with new measurements, GIMSYS uses a Kalman filter and stochastic estimation to obtain an optimal combination of the measurements with constraints derived from ionospheric physics and empirical ionospheric models. By applying time-series analysis to recent TEC maps, GIMSYS can also generate forecast TEC maps that are reasonably accurate for 2 to 4 hours. The numerous actual and potential users of the data products of GIMSYS include military, industrial, and academic organizations concerned with radio communication, navigation, mapping, scientific observations, and effects of ionospheric storms on power-distribution systems.

This program was written by Ulf J. Lindqwister; Charles D. Edwards, Jr.; Ron Muellerschoen; Xiaoqing Pi; Anthony J. Mannucci; Lawrence Sparks; Thomas Runge; Byron A. Iijima; Mark Reyes; and Brian Wilson of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-20460.

Program for Simulating Rotor Dynamics on Personal Computers

ARDS (Analysis of RotorDynamic Systems) is a public-domain computer program that simulates transient and steady-state dynamics of a rotary machine that can include as many as five interconnected flexible shafts. ARDS can be used to analyze the dynamics of such diverse machines as turbocompressors, turbopumps, gas turbines, steam turbines coupled with electric generators, power-transmission shafts, and other rotating machinery in which the flexibility of shafts is significant. Researchers at Arizona State University wrote the original version of ARDS in the FORTRAN 77 language during the early 1980s for execution on a mainframe computer. Retaining the original FORTRAN 77 language and capabilities, the code was modified into the present version, denoted ARDS-PC, for execution on personal computers. ARDS-PC is also readily convertible to a FORTRAN 90 version for personal computers.

ARDS utilizes finite-element analysis and component-mode synthesis to quickly and accurately calculate transient and steady-state rotor responses. The program includes a fourth-order Runge-Kutta integrator that uses a fixed time step specified by the user. ARDS can compute transient responses to four types of excitation: turns of entire machines about axes other than shaft axes (these turns affect rotor behavior through gyroscopic effects), variable base acceleration, variable applied forces, and suddenly applied imbalance (e.g., loss of a blade). The effects of squeeze-film dampers and dropping onto (and thus rubbing against) backup bearings and the finite stiffness of bearings (including magnetic bearings) can be included in simulations. The customary steady-state responses, including natural frequencies, critical speeds, and effect of rotor imbalance can all be calculated.

Additional functions in ARDS-PC include (1) estimating the peak response following loss of a blade without resorting to a full transient analysis; (2) calculation of sensitivity of response to input parameters; (3) formulation of optimum rotor and damper designs that are optimized in the sense that critical speeds are placed in desirable ranges or bearing loads are minimized; and (4) generation of Poincaré plots so the presence of chaotic motion can be ascertained.

ARDS-PC produces printed and plotted output. The executable code uses the full array sizes of the mainframe version and fits on a high-density floppy disc. ARDS-PC can be executed on personal computers equipped with '486 (or more capable) processors that utilize the DOS operating system with an extended memory manager.

This program was written by David P. Fleming of **Glenn Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17007.

Software for Monitoring and Controlling DSN Operations

Network Monitor and Control (NMC) Automation Assembly (AA) is a component of the NMC software system, which is used for controlling an antenna connection in the Deep Space Network. NMC AA could also be adapted to commercial applications (e.g., chemical processing), in which human operators must monitor and control multiple equipment subsystems simultaneously in real time. NMC AA is designed to reduce costs and increase efficiency and capacity by relieving human operators of labor-intensive and error-prone routine spacecraft-tracking activities. NMC AA includes software engines that communicate between automation scripts and DSN subsystems. The automation scripts are developed in the Automation Language for Managing Operations (ALMO), which is a programming language that includes specialized constructs for interacting with the subsystems. The contents of the scripts represent knowledge of operations gathered from DSN operators and engineers. The ALMO scripts are organized in a temporal-dependency network and managed via a graphical user interface that enables a human operator to monitor and control the automation at any time.

This program was written by Eva Bokor, Bryan Camilli, Manuel Gomez, Patrick Olguin, Paul Pechkam, Patricia Santos, and Marla Thornton of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*

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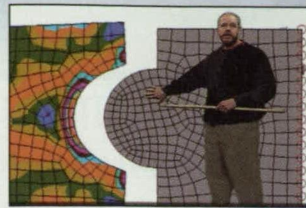

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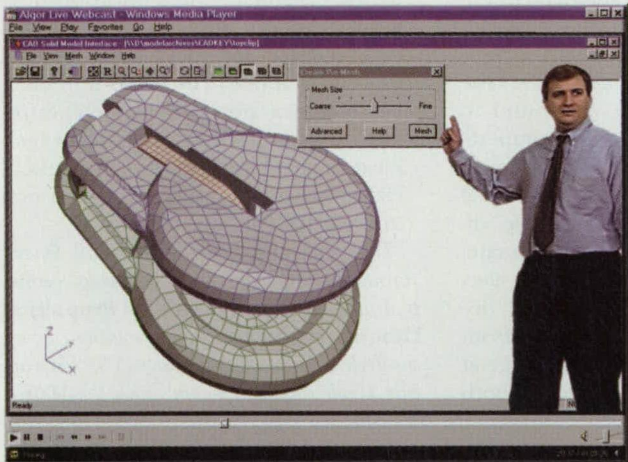

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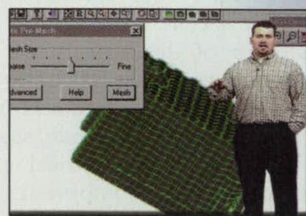

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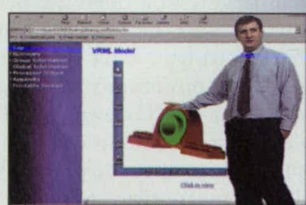

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Lithium Alkoxide Electrolyte Additives for Lithium-Ion Cells

These additives help to extend operating temperatures to as low as –40 °C.

NASA's Jet Propulsion Laboratory, Pasadena, California

Alkoxides of lithium have been found to be useful as electrolyte additives to improve the low-temperature performance of rechargeable lithium-ion electrochemical cells. As explained below, an additive of this type exerts beneficial electrochemical effects both within the bulk of the electrolyte and on the surface of the carbon anode, such that the low-temperature electrical characteristics of the cell are improved.

The discovery of lithium alkoxide electrolyte additives was made during continuing research directed toward extending the range of practical operating temperatures from the present lower limit of –20 °C down to –40 °C, and even lower if possible. This research at earlier stages was reported in "Update on Electrolytes for Low-Temperature Lithium Cells" (NPO-20407), *NASA Tech Briefs*, Vol. 24, No. 1, (January, 2000), page 56. To recapitulate: the loss of performance with decreasing temperature is attributable largely to a decrease of ionic conductivity and the increase in viscosity of the electrolyte. What is needed to extend the minimum operating temperature from –20 °C down to –40 °C is a stable electrolyte solution with relatively small low-temperature viscosity, a large electric permittivity, adequate coordination behavior, and appropriate ranges of solubilities of liquid and salt constituents.

The electrolytes investigated intensively at earlier stages of this research were made of $LiPF_6$ mixed with various proportions of aliphatic carbonates. One optimal formulation that was found to yield excellent room- and low-temperature performance is a 1.0 M solution of $LiPF_6$ in a solvent that consists of equal volume parts of ethylene carbonate, dimethyl carbonate, and diethyl carbonate. Prototype cells that contained this electrolyte exhibited high charge and discharge capacities at temperatures from –20 to –40 °C, capability for discharge at high rates, and high cycle lives at both low and room temperatures.

A lithium alkoxide additive helps to improve the low-temperature performance of a cell in the following two ways:

- A film forms on the surface of the carbon anode. Whether the anode is made of graphitic or nongraphitic carbon, the surface film acts as a solid/electrolyte interface, the nature of which is critical to low-temperature performance. Desirably, the surface film would exert a protective effect yet would remain conductive to lithium ions to facilitate intercalation of lithium. The effect of the lithium alkoxide additive is to render the surface film more favorable in these respects.
- This results in the formation of asymmetric carbonates via a disproportionation reaction, such as ethyl methyl carbonate in the electrolyte solution described above. Thus, this approach represents a novel method of introducing asymmetric carbonates, which have been identified as being beneficial to low-temperature characteristics, into electrolyte formulations.

This work was done by Marshall Smart, Ratnakumar Bugga, and Subbarao Surampudi of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

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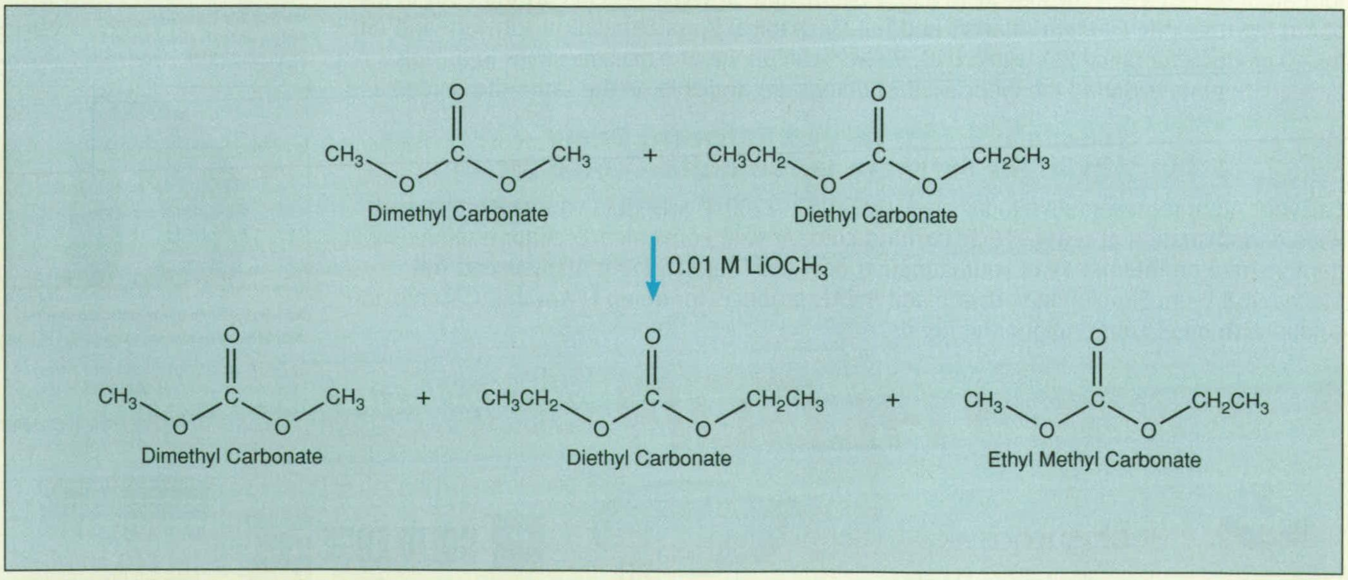


The **Formation of Asymmetric Carbonates** from a solvent mixture of symmetric aliphatic carbonates is facilitated (catalyzed) by a lithium alkoxide additive — in this case, lithium methoxide.

Aliphatic Ester Electrolyte Additives for Lithium-Ion Cells

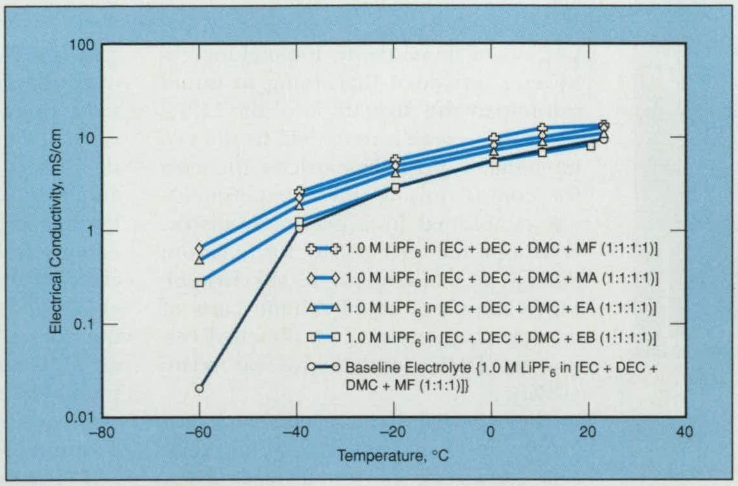
Higher-molecular-weight esters show promise for extending lower temperature limits.

NASA's Jet Propulsion Laboratory, Pasadena, California

Aliphatic esters have been found to be useful as electrolyte additives for improving the low-temperature performances of rechargeable lithium-ion electrochemical cells. The discovery of the beneficial effects of these additives was made during continuing research directed toward extending the lower limit of operating temperatures of these cells. Other aspects of this research have been described in the immediately preceding article and in prior *NASA Tech Briefs* articles referenced therein.

In experiments, the effects of aliphatic esters as additives were investigated with respect to a baseline optimal electrolyte formulation described in the noted previous articles; namely, a 1.0 M solution of $LiPF_6$ in a solvent that consists of equal volume parts of ethylene carbonate (EC), dimethyl carbonate (DMC), and diethyl carbonate (DEC). In order of increasing molecular weight, the aliphatic esters investigated were methyl formate (MF), methyl acetate (MA), ethyl acetate (EA), ethyl propionate (EP), and ethyl butyrate (EB). These esters have freezing temperatures ranging from −73 to −98 °C — lower than the freezing temperatures of the carbonate solvents. They are fully miscible into the baseline electrolyte solution. In each case, the volume proportion of aliphatic ester incorporated into the electrolyte was equal to the volume proportion of one of the carbonate solvents.

The experiments included measurements of the temperature-dependent electrical conductivities of the ester-containing electrolytes, charge/discharge tests of lithium/graphite half cells containing these electrolytes, and ac-impedance and dc-micropolarization tests to determine the effects of electrolyte compositions on the electrochemical characteristics of films that formed on the graphite electrodes. The low-temperature electrical conductivities of the electrolytes were found to be increased by the addition of the esters, the greatest increase occurring in the cases of the esters of lowest molecular weight (see figure). However, the films formed in the presence of the higher-molecular-weight esters were found to be more stable and to exhibit better kinetics for lithium intercalation/de-intercalation, especially at lower temperatures. Taking both of these trends into account, it appears that the higher-molecular-weight esters are more promising as electrolyte additives.



Electrical Conductivities Are Increased beyond that of the baseline electrolyte by the addition of aliphatic esters. Although the greatest increase of conductivity shown here occurs in the case of the ester of lowest molecular weight, other considerations favor the selection of the higher-molecular weight esters.

This work was done by Marshall Smart, Ratnakumar Bugga, and Subbarao Surampudi of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

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Ethyl Methyl Carbonate as a Cosolvent for Lithium-Ion Cells

A low freezing temperature and low viscosity contribute to low-temperature performance.

NASA's Jet Propulsion Laboratory, Pasadena, California

Ethyl methyl carbonate (EMC) has been found to be a suitable cosolvent, along with three other carbonate solvents, for incorporation into electrolytes to enhance the low-temperature performance of rechargeable lithium-ion electrochemical cells. EMC is an asymmetric aliphatic carbonate, and, as noted in the first of the two immediately preceding articles, asymmetric carbonates confer certain benefits. In the research described in that article, the asymmetric carbonates were formed *in situ*, in reactions catalyzed by lithium alkoxide additives. In contrast, the present finding that EMC is a suitable cosolvent was made by following a different approach; namely, formulating the electrolyte solvents to include an asymmetric aliphatic carbonate — EMC — in the first place.

The table shows the compositions of electrolytes used in experiments on the effects of using EMC as a cosolvent. These compositions were chosen on the basis of the expectation of the beneficial effects of adding a low-viscosity, low-melting-temperature solvent (in this case, EMC) to carbonate solvent mixtures that had previously been observed to have desirable stabilizing and passivating qualities. Another purpose for some of the choices was to minimize the proportion of EC and maximize the pro-

Concentration (Molar) of $LiPF_6$ in the Solvent	Composition of Solvent, Volume Proportions of the Constituents Listed Below			
	EC	DEC	DMC	EMC
1.0	1	1	1	0 (Baseline)
0.75	1	1	1	0
0.75	1	1	1	1
0.75	0.3	0.7	0	0
0.75	0.3	0	0.7	0
1.0	1	1	1	2

These **Electrolyte Compositions** were tested to determine the beneficial effects of incorporating EMC into the carbonate solvent mixture.

portion of low-viscosity, low-melting cosolvents, provided that doing so would not impair the dissolution of the $LiPF_6$. As in the research described in the two immediately preceding articles, the basis for comparison in these experiments was established by a previously discovered optimal electrolyte formulation; namely, a 1.0 M solution of $LiPF_6$ in a solvent comprising equal volume parts of ethylene carbonate (EC), dimethyl carbonate (DMC), and diethyl carbonate (DEC).

The experiments included charge/discharge tests of lithium/graphite half cells containing the various electrolytes, and ac-impedance and dc-micropolarization tests to characterize the films [solid/electrolyte interfaces (SEIs)] that formed on the graphite electrodes. The results of the experiments were interpreted in terms of stability of SEIs, kinetics of intercalation of lithium into graphite electrodes, and electrical conductivities of electrolytes. In the formulations studied, the addition of EMC exerted no observable adverse effects on the SEIs or on the kinetics; instead, the addition of EMC was found to reduce low-temperature film resistances and to enhance the kinetics and the discharge characteristics. The best low-temperature electrical performance was observed in the case of the electrolyte with the highest EMC content; this is consistent with the lower (relative to the other carbonate solvents) viscosity and freezing temperature of EMC.

This work was done by Marshall Smart, Ratnakumar Bugga, and Subbarao Surampudi of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*
NPO-20605

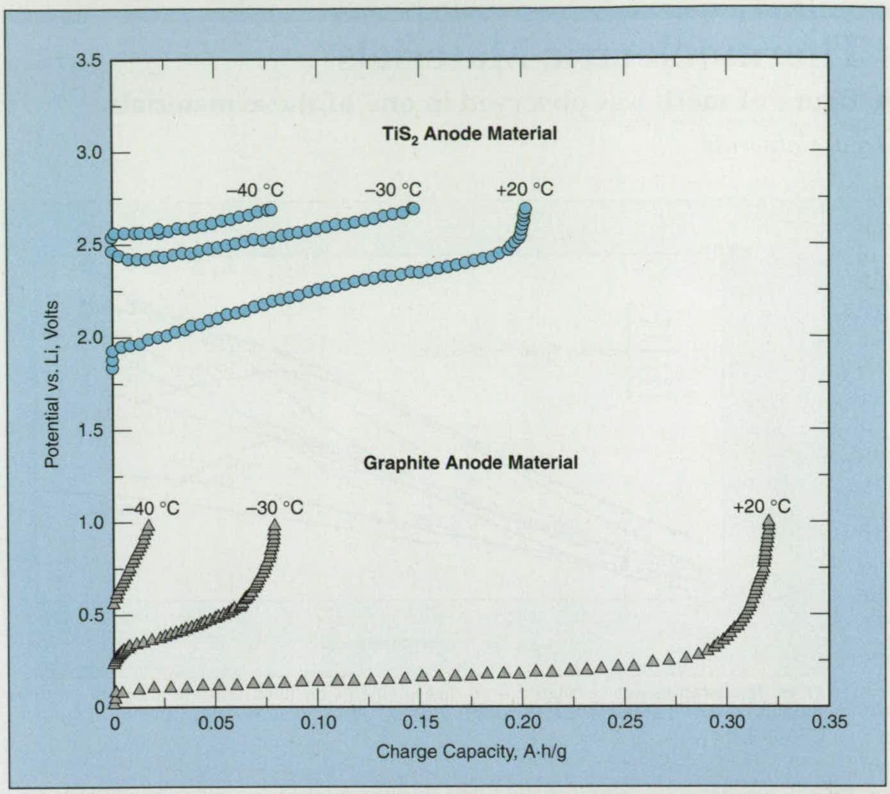
Rechargeable Li-Ion Cells Containing TiS_2 Anodes

Low-temperature performances exceed those of cells containing graphite anodes.

NASA's Jet Propulsion Laboratory, Pasadena, California

Titanium disulfide has been found to be attractive as an alternative to graphite as the anode material in rechargeable lithium-ion electrochemical cells that are required to operate at temperatures below −20 °C. By using TiS_2 as the anode material, $LiCoO_2$ as the cathode material, and a suitable low-temperature electrolyte described below, it is possible to construct cells that exhibit superior low-temperature characteristics, including relatively high charge/discharge capacities, capabilities for charging and discharging at relatively high rates, and excellent retention of capacity after repeated charge/discharge cycling.

The three immediately preceding articles report improvements in electrolytes for low-temperature, rechargeable lithium-ion cells with carbon (usually graphite) anodes. Unfortunately, in cells with carbon anodes, improvements in electrolytes may not be sufficient by themselves; this is because the performances of such cells are limited by high polarization resistances at the carbon anode surfaces. It has been conjectured that the high polarization resistances are due to the slowness, at low temperatures, of diffusion of ions through the



Specific Charge Capacities of TiS_2 and Graphite anode materials were measured at three different temperatures. One measurement (the one on graphite at –30 °C) was made at a current density of 0.04 mA/cm^2; all the other measurements were made at a current density of 0.4 mA/cm^2.

graphite bulk and through surface films (solid/electrolyte interphase) that form on carbon anodes and freeze at low temperatures. Among other things, high polarization resistances make it necessary to charge and discharge at low rates — in some cases as low as $I = C/100$, where I is the charge or discharge current in amperes and C is the nominal charge capacity in ampere·hours.

Two major reasons for choosing TiS_2 as a candidate alternative anode material are that (1) the diffusivity of Li in TiS_2 is high and (2) solid/electrolyte interphases are not expected to form on the surfaces of TiS_2 electrodes because the voltage of TiS_2 versus Li in the fully discharged condition (1.7 V) lies within the stability window of state-of-the-art electrolytes for lithium-ion cells. Because of reason (2), it is possible to use an electrolyte that contains high concentrations of low-freezing-temperature solvents that would be unsuitable for carbon anodes. One particularly attractive electrolyte turns out to consist of 1 M $LiPF_6$ in a solvent that comprises ethylene carbonate (EC), diethyl carbonate (DEC), dimethyl carbonate (DMC), and ethyl methyl carbonate (EMC) in volume proportions of 3:5:4:1. This electrolyte was developed by carefully selecting proportions of low-freezing-point solvents to suppress the freezing point; in this case, the specific volume proportions were chosen because the resulting solvent mixture remains liquid down to a temperature of –42.5 °C — below the freezing temperatures of other candidate carbonate solvent mixtures that were also tested.

For experiments to quantify the performances of TiS_2 and graphite anodes, half cells with these anodes and lithium counter/reference electrodes were constructed. The cells were tested electrochemically at room temperature (+20 °C) and at temperatures of –30 and –40 °C. The results of the tests (see figure) show that while the graphite anode material exhibits higher specific charge capacity at room temperature, TiS_2 exhibits higher specific charge capacity at the lower test temperatures.

In another experiment, a full cell containing a TiS_2 anode and an $LiCoO_2$ cathode was constructed and demonstrated to operate at an average potential of about 1.8 V at room temperature. No information on low-temperature tests of this cell was available at the time of writing this article.

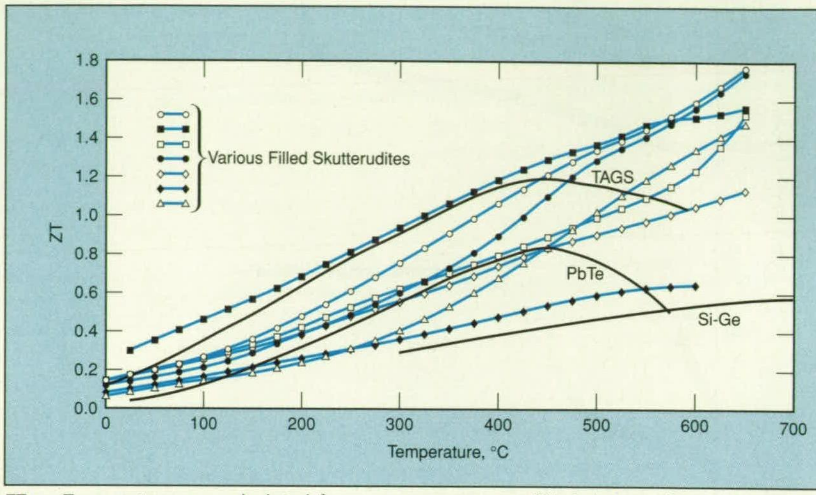
This work was done by Chen-Kuo Huang and Jeffrey Sakamoto of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*
NPO-20544

Filled Skutterudites as Thermoelectric Materials

The highest known thermoelectric figure of merit was observed in one of these materials.

NASA's Jet Propulsion Laboratory, Pasadena, California

Filled skutterudites have shown promise as semiconducting materials with superior thermoelectric properties at temperatures up to at least 650 °C. This finding is a breakthrough in a continuing investigation of the potential utility of skutterudites as thermoelectric materials. Previous results of this investigation were reported in several articles in *NASA Tech Briefs*; namely, "Skutterudite Compounds for Power Semiconductor Devices" (NPO-19378), *NASA Tech Briefs*, Vol. 20, No. 3 (March 1996), page 60; "Two Potentially Useful Ternary Skutterudite Compounds" (NPO-19409), *NASA Tech Briefs*, Vol. 20, No. 11 (November 1996), page 66; and "Preparation and Some Properties of n-Type $Ir_xCo_{1-x}Sb_3$" (NPO-19852), *NASA Tech Briefs*, Vol. 20, No. 11 (November 1996), page 94.



***ZT* vs. Temperature** was calculated from measurements on filled skutterudites and on three state-of-the-art thermoelectric materials; namely, PbTe, a Si/Ge alloy, and a Te/Ag/Ge/Sb ("TAGS") alloy.

Filled skutterudites are derived from the skutterudite crystal structure and can be represented by the formula LnT_4Pn_{12}; where "Ln" denotes one of the rare-earth elements La, Ce, Pr, Nd, Sm, Eu, Gd, Th, or U; "T" denotes Fe, Ru, Os, Co, Rh, or Ir; and "Pn" denotes one of the pnicogen elements P, As, or Sb. A skutterudite is said to be filled when empty octants in the skutterudite structure of T_4Pn_{12} are filled with rare-earth atoms.

Some of the filled skutterudites of various compositions prepared by a combination of melting and powder-metallurgy techniques have shown exceptional thermoelectric properties in the temperature range of 350 to 700 °C. Both p-type (electron-acceptor) and n-type (electron-donor) conductivities have been obtained; this is fortunate in that to be functional, a thermoelectric device must contain layers of both types.

The thermoelectric figure of merit, *ZT*, is given by $ZT = S^2T/\rho\lambda$, where S is the Seebeck coefficient, T is the absolute temperature, ρ is the electrical resistivity, and λ is the thermal conductivity. The figure shows *ZT* values obtained from measurements on several filled skutterudites and on other, state-of-the-art thermoelectric materials. One specimen exhibited *ZT* of almost 1.8 at a temperature of 650 °C; this is the highest *ZT* ever obtained since the beginning of thermoelectric technology in the 1950s. By manipulating the nominal compositions and doping concentrations of filled skutterudites, it may be possible to obtain similarly high *ZT* at lower and/or higher temperatures. These high-performance thermoelectric materials could be used to make thermoelectric power generators, coolers, and detectors that would operate with efficiencies greater than those of the corresponding devices now in use and could thus be useful in a greater variety of applications.

This work was done by Jean-Pierre Fleurial, Alexander Borshchevsky, Thierry Caillat, Donald Morelli, and Gregory Meisner of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

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Expendable Composite-Layup Dies From Rapid-Prototype Masters

Small production runs of intricate parts can be accomplished at relatively low cost.

Lyndon B. Johnson Space Center, Houston, Texas

A method that exploits rapid prototyping has been conceived to reduce the time and cost associated with the production of small quantities of composite-material parts that have complex shapes. In this method, mandrels and dies used in forming composite layups are sized and shaped by molding them on rapid-prototype masters and are made of disintegrating mold material (DMM). The method is particularly suitable for manufacturing ventilating air ducts and water ducts for the International Space Station and manifolds and ducts for low-temperature [<350 °F (<177 °C)] fluids in aircraft and other vehicles. For the space program, this method is most advantageous when the quantities desired are low — typically fewer than 10 copies of the same manifold or other design for a specific application.

In a related prior method, master parts are made of plaster; fabrication is difficult, guided by standard paper drawings, and often subject to workmanship errors. In this prior method, plaster is cast against a plaster master part, then split along appropriate lines to create a slush mold. Next, the slush mold is filled with DMM, which is a special plaster. The part thus formed in DMM is then used as a die or mandrel for layup of a composite-material part. The DMM mandrel is not reusable; it must be remade for each part to be manufactured. The temporal and monetary costs of building the master part and the slush mold and associated tooling are often greater than the other costs of the three or four detailed copies typically manufactured from each master part.

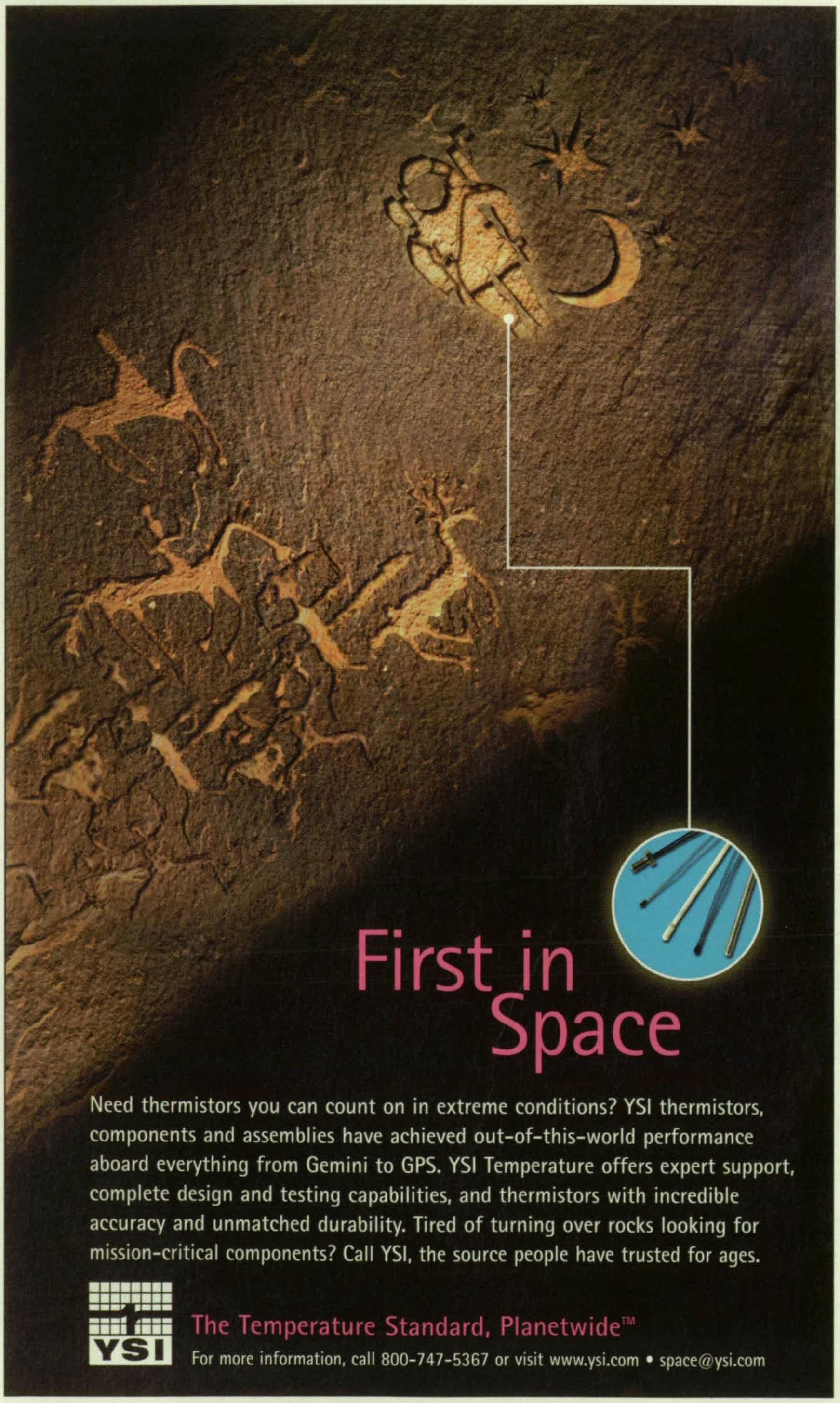
In the present method, neither a plaster master nor a slush mold is used. Instead, a master is made by rapid prototyping. DMM is then cast against the master. Once the DMM has been cured, the workpiece is placed in an oven at a temperature 225 °F (107 °C). When the DMM has been softened by heating, it is peeled away from the master. The resulting piece of DMM becomes a mandrel or mold that can be used in the custom-

ary manner for fabricating the desired composite-material part.

In comparison with the prior method, the present method saves considerable time and money. These savings are attributable mostly to elimination of the slush molds and associated tooling. In one application at Johnson Space Center, the method was found to cut weeks off the time needed to build the first part and to reduce the cost of the part by more than \$8,000. The present method also affords greater accuracy, tolerances of ±0.005 in. (≈0.13 mm) being normal. The present method also eliminates the need for reworking masters because the rapid-prototype masters are made from computer-aided-drawing data. The total saving, relative to the prior method, is expected to amount to about 75 percent; this translates to >\$240,000 per year at NASA's Palmdale, California site alone.

The present method has also been considered for use in a Marshall Space Flight center program in which a few composite-material parts are fabricated by, among other things, wrapping tapes directly on a stereolithographic master. The present method has shown potential to enhance the program by making it possible to reduce the number of steps in fabricating the master and increasing the accuracy of the master.

This work was done by Robert E. Clark, E. Wayne Shick, Ernest L. Broaden, and Fernando Schemel of Boeing North American, Inc., for **Johnson Space Center**. *For further information, contact the Johnson Space Center Commercial Technology Office at (281)483-0474. MSC-22928*



Punches and Dies for Rounding Corners of Metal Sheets

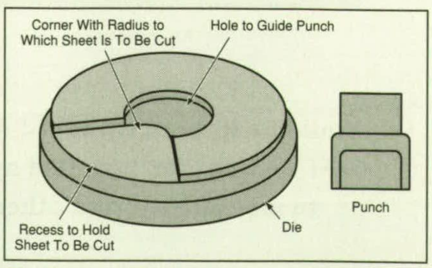
Corners can be formed to desired radii without sawing, snipping, or filing.

Ames Research Center, Moffett Field, California

Punch-and-die sets have been designed for use in rounding corners of rectangular metal sheets to specified radii. One of the traditional procedures for rounding a corner on a rectangular metal sheet is to first make a rough cut with a band saw and/or hand metal snips, then to file the roughly cut edge; this procedure is time-consuming and does not result in an accurate radius. The use of a punch-and-die set of the present type takes less time and results in a corner with an accurate radius.

The figure shows a punch and die of the present type. Of course, the dimensions of the punch and die must be chosen to suit the thickness of the metal sheet and the corner radius to be formed. Thus far, punch-and-die sets have been made for sheet thicknesses up to 0.125 in. (≈3.2 mm) and corner radii from 0.2 to 2 in. (≈ 5 to 51 mm).

This work was done by Cecil L. Wachsman of **Ames Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Manufacturing/Fabrication category. ARC-14230*



The **Punch-and-Die** can be used to cut a corner of a rectangular metal sheet to a desired radius. This is a simplified drawing; some details have been omitted for clarity in depicting basic shapes.

Model of Pyrolysis of Biomass in a Fluidized-Bed Reactor

Complex dynamics and heat transfer are represented more realistically than in prior models.

NASA's Jet Propulsion Laboratory, Pasadena, California

A mathematical model has been formulated to describe the pyrolysis of biomass in a bubbling fluidized-bed reactor. The reactor is a vertical cylinder that contains a mixture of biomass particles and sand. Superheated steam enters the reactor through holes in the bottom and flows out freely at the top. The sand is a high heat capacity medium used for heating the biomass. The biomass particles, initially at room temperature, are introduced into the already hot reactor and become heated primarily through contact with the sand. Upon reaching a threshold temperature, the biomass particles undergo chemical reactions, the gaseous products of which are carried away by the flow of steam. The "bubbles" are regions of the fluidized bed that are mostly devoid of particles; these regions occur as a result of the interaction of the turbulent gaseous flow with the particles.

The mathematical model is one of multiphase flow. The mixture of biomass and sand is regarded as a particulate phase divided into two classes of particles that interact with a flowing gas phase. Initially, the solid biomass is regarded as consisting of three chemical species: cellulose, hemicellulose, and lignin. From each of these initial species, two new solid species are generated during pyrolysis: an "active" species and a char. The gas phase is regarded as consisting of the original carrier gas (steam), plus tar and gas that are generated through pyrolysis.

The model includes equations for the conservation of mass, momentum, enthalpy, and chemical species. The conservation equations for the particles are derived from the Boltzmann equations through ensemble averaging. The particulate-phase stresses are expressed as a tensor sum of collisional and Reynolds contributions; contributions from collisions between particles of different classes are included. The conservation equations for the gaseous phase are the Navier-Stokes equations augmented by the species and energy equations and by the perfect gas law. A distinctive feature of these equations are the source/sink terms portraying the dynamic interaction between particles and gas phase.

Stresses in the gaseous phase are expressed as the sum of Newtonian and Reynolds (turbulent) contributions. Transfer of heat between phases, and between particles in various classes (e.g., as a result of collisions between biomass and sand particles) is taken into account.

Unlike most models of turbulent flows of gases in fluidized beds, this model does not contain the Boussinesq approximation, which would imply that the stress and strain-rate tensors are aligned. Such alignment is not consistent with the recirculating flows that occur in fluidized beds. Instead, in this model, turbulence is represented by the equations of the full differential Reynolds stress model (DRSM) for two-phase flows. Some of the terms in the DRSM equations are mathematical submodels that have yet to be defined. It will be necessary to complete the modeling of Reynolds stresses for both the gaseous and the particulate phases in order to close the system of governing equations.

The model is extremely complex because of the coupled nature of the dynamic and thermodynamic evolution of the phases, and because of the turbulent features of the gaseous carrier and particulate flows. Because many of the aspects of the model are novel, it is expected that the first numerical simulations to be performed by use of the model will be those of sand/biomass dynamics in absence of heat transfer, turbulence, or chemical reactions. The results of the first simulations should enable the validation of the parts of the model that represent the dynamic interaction between phases and the particulate stress tensor.

This work was done by Josette Bellan and Danny Lathouwers of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category. NPO-20708*

System for Delivering Gas Samples to Multiple Instruments

John F. Kennedy Space Center, Florida

A system that samples gases at multiple remote locations and delivers the gases to two or possibly more gas-monitoring instruments (e.g., mass spectrometers) has been developed. The system includes a transport (suction) pump that draws the gases from the sampling locations, through transport tubes, into a plenum, which is large enough to act as a buffer against changes in pressure in the transport tubes. Connected to each transport tube at a location near the plenum are two or more sample tubes that are, in turn, connected to manifolds of sample-selector valves through which gases are drawn into the instruments. Each instrument is equipped with a sampling (suction) pump that draws gas from one of the transport tubes that has been selected by opening the corresponding sample-selector valve. Each sampling pump is operated under feedback flow and pressure control to maintain a steady instrument-inlet pressure needed to ensure stable instrument readings. The sample flow thus diverted from the transport tube is kept to one-fifth or less of the transport flow in order to minimize the perturbation of the transport flow and thus, further, minimize any effect of one instrument on the other.

This work was done by Barry Davis, Carolyn A. Mizell, and Frederick W. Adams of **Kennedy Space Center** *and Timothy Griffin, Curtis M. Lampkin, Guy Naylor, and Richard J. Hritz of Dynacs Engineering Co., Inc. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category. KSC-12123*

Atmospheric Source of Atomic Oxygen for Cleaning Paintings

A vacuum chamber is no longer necessary.

John H. Glenn Research Center, Cleveland, Ohio

A portable apparatus that operates at atmospheric pressure generates a beam of monatomic oxygen. The apparatus is designed to be used in a dry, noncontact process for removing organic contaminants from the surfaces of paintings. Organic contaminants that can be wholly or partly removed by use of this apparatus include some deposited in acts of defacement (e.g., lipstick and marks left by felt-tip and ball-point pens) and some deposited from fire (e.g., soot and charred binder). In some cases, this apparatus may make it possible to restore works of art that were previously counted as lost.

The use of monatomic oxygen to remove undesired organic materials from the surfaces of paintings was reported in several articles in previous issues of *NASA Tech Briefs*; namely, "Atomic Oxygen Removes Varnish and Lacquer From Old Paintings" (LEW-16031), Vol. 20, No. 4 (April 1996), page 61; and "Cleaning Soot From Oil Paintings With Monatomic Oxygen" (LEW-15896), *NASA Tech Briefs*, Vol. 20, No. 10 (October 1996), page 110. Monatomic oxygen reacts with carbonaceous deposits on the surfaces of paintings, converting the carbon to CO and CO_2 and converting any hydrogen content of the deposit to H_2O vapor. Conventional techniques for cleaning paintings involve the use of solvents, which are not effective in some defacement cases and cases of severe fire damage. In contrast, the use of monatomic oxygen causes the removal of carbonaceous deposits at controlled rates, and cleaning can be stopped at any point.

The cited prior articles describe placing each painting to be cleaned in a vacuum chamber, where it was exposed to monatomic oxygen from either a plasma or a beam source. The present atmospheric-pressure apparatus makes a vacuum chamber unnecessary. In this apparatus, monatomic oxygen is generated in a dc arc in a mixture of oxygen flowing at rate of 0.1 to 0.2 L/min and helium flowing at a rate of 4.3 L/min. The role of the helium is to inhibit the recombination of monatomic oxygen into diatomic oxygen.

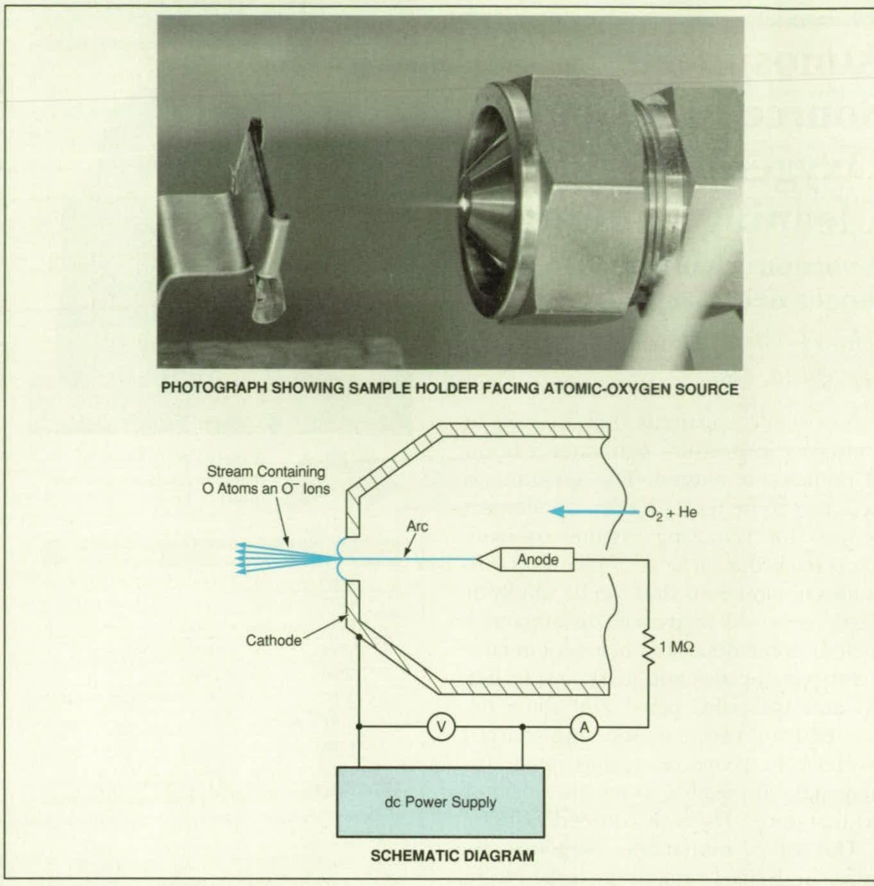


Figure 1. A **Stream That Contains O Atoms and O^- Ions** is generated in a dc arc in a flowing He/O_2 mixture.

The arc is struck between (1) a cathode in the form of a stainless-steel disk containing a 3.175-mm-diameter circular orifice on a truncated cone at one end of a plenum through which the gas mixture flows and (2) an anode in the form of a tungsten needle inside the plenum, 1.6 mm upstream from the orifice. The arc is powered by a 7-kVdc supply in series with a 1-MΩ current-limiting resistor. The arc is blown through the orifice, giving rise to a stream of oxygen ions and charge-exchange neutral oxygen atoms that are propelled about 1 cm downstream from the orifice. These oxygen species can react with organic materials exposed to the stream.

A painting to be cleaned is typically placed about 8 mm downstream from the orifice. Because the spot that is cleaned by exposure to the stream is only 3 to 5 mm wide, it is necessary to translate the apparatus gradually along the painting surface to clean a larger area. The apparatus was used to clean lipstick defacement from an Andy Warhol painting. As shown in Figure 2, the lipstick was completely removed.

This work was done by Bruce A. Banks and Sharon K. Rutledge of **Glenn Research Center** *and Edward Sechkar and Thomas Stueber of Dynacs Engineering Co., Inc. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16971.

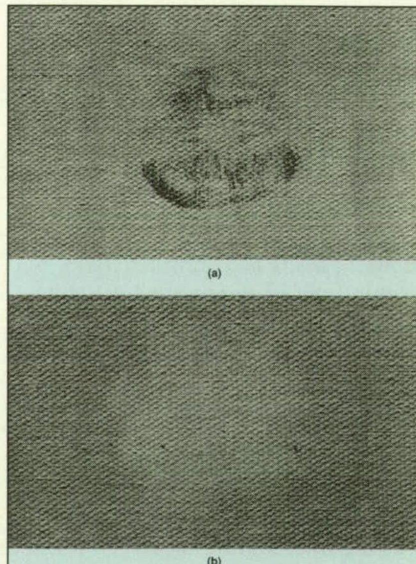
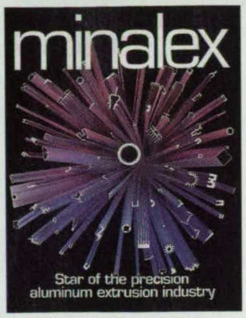


Figure 2. The **Effectiveness of Lipstick Smudge Removal** on Andy Warhol's painting, "Bathtub," is shown in closeup photographs: (a) Before atomic oxygen cleaning and (b) after atomic oxygen cleaning.



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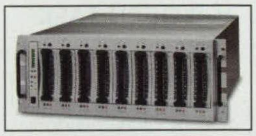

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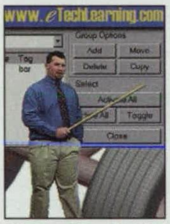

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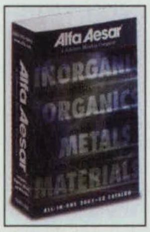

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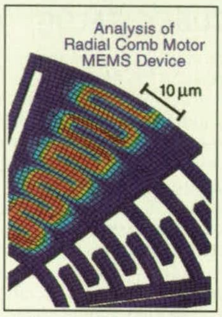

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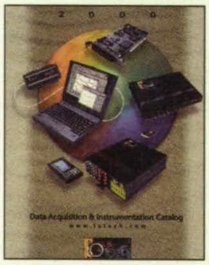

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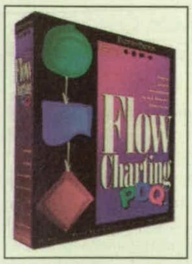

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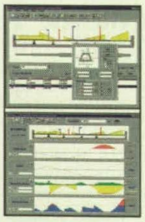

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For More Information Circle No. 623

Information Sciences

General-Purpose Wavelet Program

This program affords a variety of capabilities that are especially useful in wavelet analysis.

Stennis Space Center, Mississippi

"S+Wavelets" is the name of a computer program that implements a suite of mathematical "tools" for wavelet analysis of signals (including two-dimensional signals that represent images.) Wavelets, being localized in both time and frequency (or space and wave number), serve as means for transforming and extracting information from signals that have temporally or spatially varying properties. In a sense, wavelet methods combine the best features of time and frequency methods (e.g., Fourier-transform methods). Modern wavelet research began in the mid-1980s, but until now, there has been no commercially available, general-purpose software to support rapid prototyping for research on, and application of, wavelets. S+Wavelets satisfies the need for such a computer code.

S+Wavelets provides a variety of transform objects for one- and two-dimensional sets of data, including the following:

- The discrete wavelet transform with orthogonal and biorthogonal wavelets;
- Multiresolution analysis and decompositions;
- Wavelet-packet and cosine-packet transforms with best-basis selection;
- Matching pursuits decompositions;
- Robust and outlier-resistant wavelet transforms;
- Translation-invariant (nondecimated) wavelet transforms;
- Decompositions of signals into atomic waveforms; and
- Estimates of signals through wavelet shrinkage

S+Wavelets is available as part of a software system called "S-PLUS." S+Wavelets supports such basic S-PLUS functions as print, plot, and summary, specializing these features and functions for wavelet objects. Other basic S-PLUS generic functions supported in S+Wavelets include subscript and assignment operators, arithmetic and logical operators, mathematical functions, and a suite of "tools" that assist in visualization of data. The visualization tools include autocorrelation-function plots, box plots, bar plots, dot charts, histograms, and quantile-quantile plots. All of these functions are specialized for wavelet objects; for example, in the case of a discrete wavelet transform, side-by-side box plots would depict wavelet coefficients grouped by resolution levels.

S+Wavelets introduces several new functions that are especially useful for wavelet analysis. These include provisions for displaying a palate of "interesting" views, time-scale and time-vs.-frequency plots, transfer-function plots, evaluation of Fourier transforms of wavelets, plots of energy-concentration efficiencies of waveforms, and plots for visualizing the type of transform basis selected for analysis.

S+Wavelets offers the following other capabilities and features that are important for wavelet analysis:

- Perfect Reconstruction – All transform objects can be inverted to recover original signals to within round-off errors.
- Dual Implementation in S-PLUS and C – Most of the algorithms in S+Wavelets are implemented in both the S-PLUS and C languages for flexibility and efficiency. The S-PLUS versions are used to make modifications and extensions, while the C versions are ordinarily used to perform computations.
- Ability to Create New Wavelet Filters – Users can create their own wavelets and wavelet filters for use in addition to, or in place of, built-in wavelets and filters.
- Support for Arbitrarily Sized Signals – Most transforms can be applied to a signal or image of any size, and are not restricted to sample sizes divisible by integer powers of 2.
- Variety of Boundary Conditions – Boundary-treatment rules and boundary conditions accommodated in S+Wavelets include periodic, reflection, zero, polynomial extension, and internal wavelets.
- Wavelet Matrix Filter Operations – Matrix filter operations can be created for wavelet transforms. This is useful for education and research.

This work was done by Andrew Bruce and Hong-Ye Gao of MathSoft, Inc., for **Stennis Space Center**.

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

STATSCI Division MathSoft
1700 Westlake Ave. North, Suite 500
Seattle, WA 98109

Refer to SSC-00076, volume and number of this NASA Tech Briefs *issue, and the page number.*

Automated Generation of Reports of Mars Rover Operations

NASA's Jet Propulsion Laboratory, Pasadena, California

A document describes a system for the automated generation of reports of operations of a robotic exploratory vehicle (rover) on Mars. The automated report-generation system supplants a predominantly manual system, thereby making more information available in less time and reducing the probability of data-entry errors. The automated report-generation system has been incorporated into the Web Interface for Telescience, WITS, and utilizes information in the WITS database. (Described in several prior *NASA Tech Briefs* articles, the WITS is an Internet-based software system that enables geographically dispersed scientists and engineers to monitor and command a rover.)

This work was done by Paul Backes and Jeffrey Norris of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the document, "Automated Rover Sequence Report Generation," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Information Sciences category.*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-21123.

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Free CAD Models

BAND-IT, Denver, CO, offers downloadable 2D and 3D models of more than 700 products from their Web site. 3D IGES models customized for 27 different systems, 3D STEP, and 2D DXF six-view layouts are available. The company manufactures and supplies stainless steel clamping, fastening, and identification systems. **www.band-it-idex.com**

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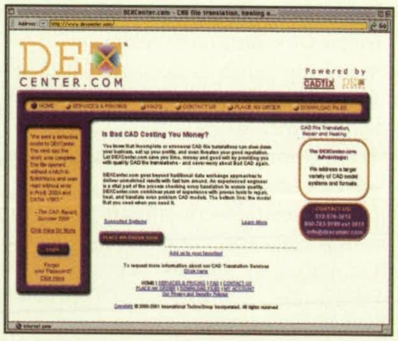
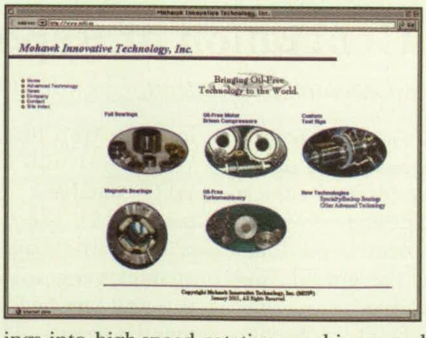
Electronic engineers can design, spec, view, price, and printout information on electronic enclosures via a new Web site from Equipto Electronics Corp., Aurora, IL. The site includes technical drawings, and a form that provides an instant parts list and prices on any electronic cabinet. The site also can be used to establish bills of materials and determine budgets. **www.equiptoelec.com**

CAD Model Repair

International TechneGroup, Milford, OH, has introduced DEXCenter.com™, an on-line service for CAD model repair, healing, and translation. It provides translation between systems and formats such as I-DEAS, UGS, Pro/ENGINEER, CATIA, Parasolid, IGES, STEP, and STL. Other tools available through the site include CADfix™ for model healing and repair, and CAD/IQ™, a model quality, interoperability, and six sigma testing tool. **www.dexcenter.com**



Machinery Bearings



Mohawk Innovative Technology, Albany, NY, has redesigned its Web site to include more information on the company's product development and technology capabilities. The company integrates its oil-free bearings into high-speed rotating machinery such as gas turbine engines and compressors. Also described on the site are compliant foil bearings and magnetic bearings. **www.miti.cc**

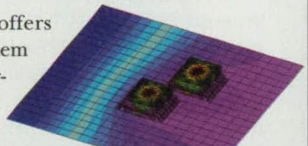
New on DISK

3D Simulation

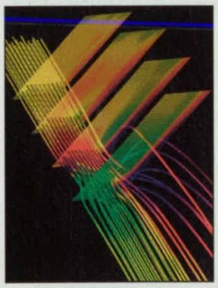
ShapeSnatcher 3.0 from Eyetronics, Los Angeles, CA, is an integrated software package that creates high-resolution 3D models from 2D photographs. The package contains ShapeSnatcher 3.0, ShapeMatcher 2.0, ShapeReducer 3.0, Mapping Tools v2.0, and Xtrusion v2.0. ShapeSnatcher transforms a slide projector and digital camera into a 3D scanning and modeling system. The package features a built-in absolute scale in the calibration file, automatic reading of associated texture files, an "undo" function, automatic checking for OpenGL-compatible graphics cards, and a high-resolution texture map that maintains the original image size and maps onto the reduced-sized model. **Circle No. 727**

Thermal Analysis

Harvard Thermal, Harvard, MA, offers Version 6 of the Thermal Analysis System (TAS) thermal modeling software featuring SyncroMesh™, which allows users to create an interface between different parts of a model without having the element mesh agree. A detailed model of an electrical component can be placed on a course representation of the board and solved for temperatures. It can then be moved or duplicated, and then resolved without modifications. The system also includes two-button automeshing, vector-based heat loads, and heat flux contour plots. **Circle No. 728**



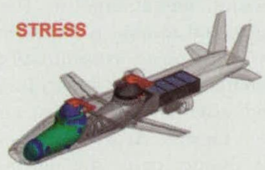
Technical Plotting



Amtec Engineering, Bellevue, WA, has announced Tecplot® Version 9.0 technical plotting software with 2D and 3D capabilities for visualizing technical data from analyses, simulations, and experiments. It uses OpenGL® to interactively visualize, explore, analyze, and virtually "fly" through large 2D and 3D data sets consisting of millions of data points. It can load and plot data organized in a variety of grid structures that are used in computer programs to simulate physics like fluid dynamics, electromagnetics, and heat transfer. **Circle No. 730**

Simulation and Analysis

ANSYS, Canonsburg, PA, offers DesignSpace® Version 6.0 up-front simulation software for confirming design assumptions and predicting product performance early in the design process. It features parametric simulation, thin sheet-metal capability, advanced non-linear contact, fatigue, and meshing controls. Users can view CAD parameters in DesignSpace and select those they wish to change. Those parameters, as well as material properties and loads, are assembled into a scenario table, and the software solves the scenarios and provides a "what-if" results summary. Productivity enhancements include an oversized model viewing window, interactive results displays, context-sensitive dialog boxes, customizable wizards, and a simulation "details" window. **Circle No. 731**



New on the MARKET

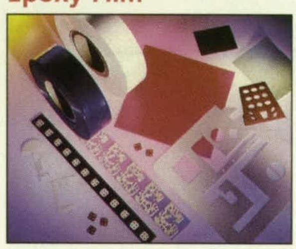
Infrared Thermometer

The OS540 portable infrared thermometer from OMEGA Engineering, Stamford, CT, is designed for non-contact temperature measurement applications, including diesel and fleet maintenance, electrical, HVAC/R automotive, in-process temperature measurement, and plastics molding. Features include circle or dot laser sighting, 9-volt battery, response time of 500 ms, and a temperature range from -20 to 420° C. It also offers resolution of 1°C/1°F and spectral response of 6-14 mm. **Circle No. 721**

Document Solutions

Xerox Engineering Systems, Stamford, CT, has introduced the Synergix 8825 DS, 8830 DS, and 8855 DS printers, each of which combines with the Synergix Scan System to create integrated solutions. All Synergix systems are modular, scaleable, and upgradeable for CAD, commercial reprographics, engineering departments, architectural firms, construction, utilities, and manufacturing. The Synergix Scan System processes smaller, lower resolution documents and automatically adjusts image quality. Features include background suppression, thick document handling, a flat document stacker that retains the order of document sets, batch mode, 256 grayscale conversion from full-color originals, and factory-aligned sensors that remain permanently aligned and require no manual recalibration. **Circle No. 725**

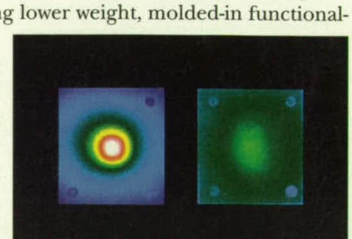
Epoxy Film



National Starch and Chemical, Bridgewater, NJ, offers PF2010 silver-filled epoxy film, an unsupported epoxy adhesive that provides thin, uniform bond lines with electrical and thermal properties. Typical properties include an aluminum-to-aluminum lap shear of over 2,400 psi, thermal conductivity at 121°C of 3.5 W/m°K, and volume resistivity of 0.0002 ohm-cm. It has a room-temperature work life of 90 days, and a long shelf-life when stored frozen. The film is available in sheet, tape, or die-cut pieces for specific bond lines. **Circle No. 722**

Thermally Conductive Polymer

CoolPoly® thermally conductive polymers from Cool Polymers®, Warwick, RI, is an alternative to metals, ceramics, and non-thermally conductive plastics. The polymers are suitable for use in applications such as industrial equipment, lighting, electronics, power electronics, medical, and automotive. The injection-molded polymer can replace metal and ceramic parts, offering lower weight, molded-in functionality and parts consolidation, elimination of post-machining and assembly operations, and heat transfer. As a replacement for plastics parts, the polymer offers elimination of "hot spots," effective heat transfer, and low coefficient of thermal expansion. **Circle No. 724**

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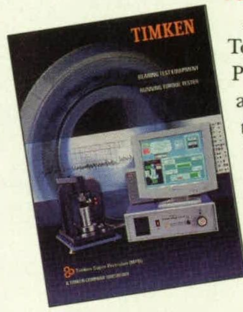
New LITERATURE

RF and Microwave Products

Giga-tronics, San Ramon, CA, has issued a catalog of microwave synthesizers, power meters, RF signal generators, and VXI instruments. The company designs, manufactures, and markets a line of RF and microwave instruments with applications in wireless communications, satellite transmission, aircraft navigation, and electronic defense. A sensor selection chart matches products to exact measurement requirements. **Circle No. 710**

Thermoplastic Parts

RTP, Winona, MN, offers a technical brief describing physical property enhancements and the cost savings associated with compounds containing DuPont Fluoroguard® perfluoropolyether (PFPE) synthetic oil. The compounds eliminate "plate-out" associated with PTFE and increase throughput. Physical property enhancements include improved wear resistance, fatigue resistance, and minimized scratches or marring. **Circle No. 711**



Torque Tester

A brochure describing the RT2C-E Running Torque Tester is available from Timken Super Precision, Keene, NH. The tester determines the actual running torque inherent to a rotating system. A user can diagnose problems in existing bearing equipment or identify problems prior to use. Problems such as retainer hang-up, ball or race surface problems, contamination, internal geometry, and structural defects can be determined on a single bearing or a group of bearings through sampling. **Circle No. 712**

Contract Manufacturing

United for Excellence (UFE), Stillwater, MN, offers a brochure describing its product engineering, injection molding, mold manufacturing, and contract manufacturing services. These capabilities are for the design, development, and production of precision components or complete products. The services can be used individually or as part of an integrated program from design to final assembly. **Circle No. 713**

Standoff Fasteners

A four-page bulletin from PEM Fastening Systems, Danboro, PA, profiles PEM® SNAP-TOP® all-metal standoffs designed to attach and space PC boards and subassemblies without using screws or other threaded fastening hardware. Upon installation, the fasteners utilize a spring action to hold PC boards and subassemblies, while allowing for attachment and removal of boards or panels with snap-on/snap-off action. **Circle No. 715**

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